Monitoring & Evaluating the Ecological Condition of Iowa's Shallow Lakes: 2010 to 2012 Pre- and Post-Renovation

Submitted by:

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Table of Contents

List of Tables

List of Figures

Page

List of Figures (Continued)

Page

INTRODUCTION

Over the past century, the ecological integrity of Iowa's shallow lakes (mean depth of <5 feet) and large wetland complexes has declined significantly due to changes in land use, altered hydrology, increased non-point source pollution, and the invasion of exotic rough fish. These landscape level changes have resulted in the severe decline of wetland habitat conditions and foraging quality for waterfowl and other migratory birds. In an effort to reverse this damage, the Iowa Department of Natural Resources (Iowa DNR) and Ducks Unlimited, Inc. (DU) launched an aggressive partnership aimed at restoring several highly degraded shallow lakes and large wetland complexes located within Iowa's Prairie Pothole Region.

The Iowa DNR and DU have been working together to improve wetlands and waterfowl habitat for over 35 years. Since 1973, the Iowa DNR has contributed well over $1,000,000 to DU's state grants program, which provides critical funding for habitat conservation work in Canada. This ongoing and significant contribution represents a strong commitment by the Department to conserve quality habitat in areas of Canada that serve as the primary source of waterfowl harvested by Iowa hunters. In 1984, DU opened its Great Plains Regional Office and began conserving wetland and waterfowl habitat across the upper Midwest, including many parts of Iowa. Since then, the Iowa DNR and DU have partnered on countless projects across the state on private, county, state, and federally-owned lands.

In 2006, the Iowa DNR and DU signed a five-year Cooperative Agreement to enhance and restore seven highly degraded priority shallow lakes and large wetland complexes. These restoration projects were identified within strategically targeted Prairie Pothole Joint Venture (PPJV) and *Living Lakes* Emphasis Areas (Figure 1). Each site is perpetually protected, owned, and managed by the Iowa DNR. Under this agreement, both partners pledged $500,000 toward the restoration of these sites. Within the first three years of launching this program, the Iowa DNR and DU have invested over $1.2 million to restore four priority shallow lakes and large wetland complexes (Big Wall Lake, Diamond Lake, Four Mile Lake, and Dan Green Slough). Restoration efforts continue on the remaining sites.

To evaluate the success of DU's current *Living Lakes* program and garner further public support for future projects, the Iowa DNR expanded the Shallow Lakes Monitoring Program to include a number of non-restored sites, while continuing to monitor all restored sites. Monitoring data collected during 2006-2009, from a number of shallow lakes with restoration potential, has confirmed that the majority of these sites have little to no emergent aquatic plant growth, exhibit extremely high turbidity and nutrient levels, and are dominated by exotic rough fish. These results confirmed that restoration efforts are desperately needed on these sites.

The restoration techniques implemented are dependent on the conditions of the site, but typically include the design and installation of water control structures, fish barriers, and pumping systems. These structures allow Iowa DNR managers the ability to manipulate water levels, eradicate nuisance rough fish, and optimize habitat conditions for waterfowl and other wetland-dependent species. Within only a few years of launching this program, significant improvements in water quality, aquatic plant growth, and overall migratory bird use have been documented at these restored sites. Water clarity readings at one of the restored sites, Diamond Lake, increased from a visibility of less than eighteen centimeters pre-restoration, to over one hundred centimeters post-restoration. Similarly, aquatic plant species abundance and biodiversity increased significantly from only four aquatic plants species documented during pre-restoration monitoring to over twenty-four different species post-restoration. If the *Living Lakes* Partnership continues to grow, increased funding support will be needed to help expand the DNR's Shallow Lakes Monitoring Program to include both restored and non-restored sites.

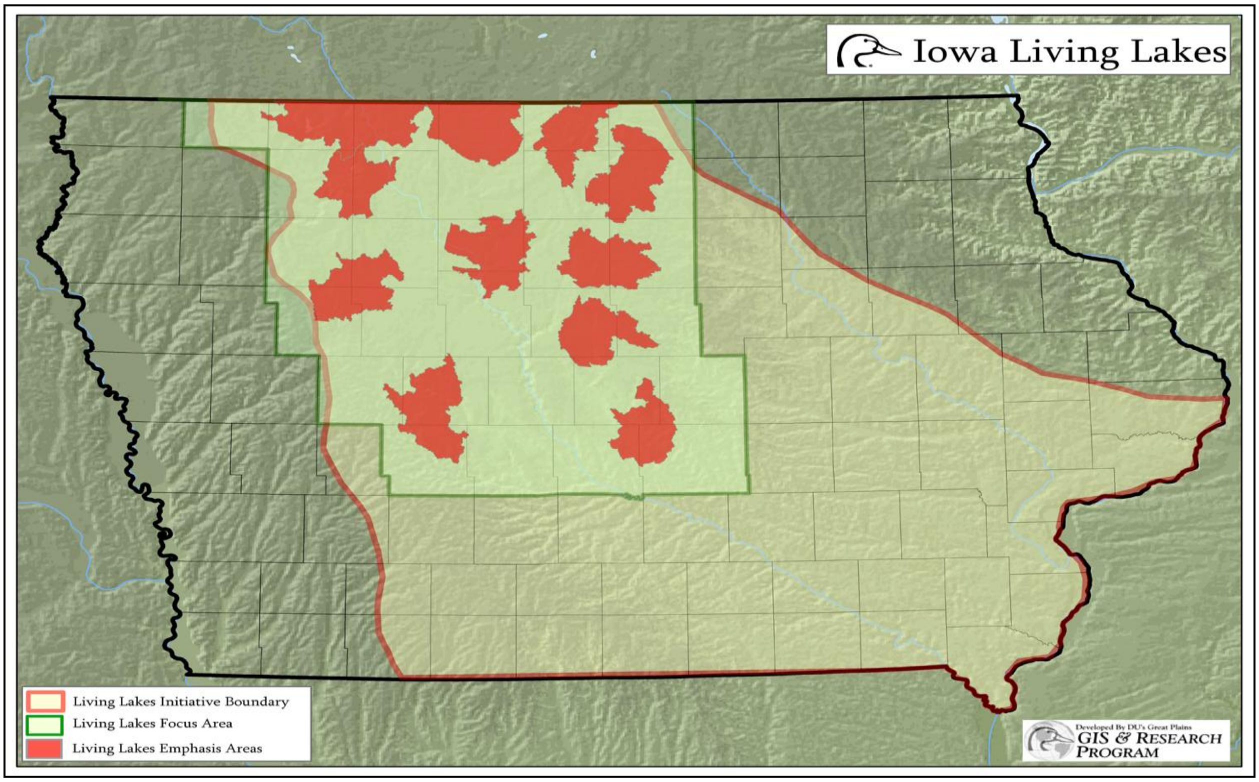


Figure 1. Iowa's *Living Lakes* Initiative habitat conservation "Emphasis Areas".

PROJECT GOALS AND OBJECTIVES

The primary goals of this project were to: (1) significantly expand the number of shallow lakes monitored by the Iowa DNR to include sixteen restored and non-restored shallow lakes; (2) continue long-term monitoring efforts on restored shallow lakes; and (3) evaluate water quality improvements and ecological benefits that directly resulted from these targeted conservation investments. In order to increase the program capacity to monitor more shallow lakes, the Iowa DNR was awarded $75,000 ($25,000/year payable over three years) of funding from the Prairie Pothole Joint Venture to continue monitoring efforts on sixteen shallow lakes and wetlands. After negotiations, DU and the Iowa DNR agreed to provide $76,800 ($76,500 cash & $300 in-kind) of matching funds for a total three year investment of $151,800.

The primary objectives of this three year project were to expand the number of shallow lakes studied by: (1) continuing monitoring efforts on four restored sites; (2) expanding monitoring efforts to include new sites with the potential for restoration; and (3) analyzing long-term monitoring data to determine temporal changes in water quality and ecological conditions following restoration activities. The results of this project provide valuable scientific information about the physical, chemical, and biological factors that affect the overall health and functionality of Iowa's shallow lake systems to improve future conservation planning and management decisions.

METHODS

In order to accurately establish baseline ecological conditions and assess temporal changes in habitat conditions, the Iowa DNR collected pre- and post-restoration monitoring data at each site. The Iowa DNR conducted baseline monitoring from 2006-2009. Each site shared similar physical, chemical, and biological characteristics, yet each possessed a unique trophic structure and stressors. The proposed sampling regime included physical, chemical, and biological parameters. These methods were developed by the Iowa DNR's Watershed Monitoring and Assessment Section (WMAS) and were based on U.S. Environmental Protection Agency (EPA) water quality monitoring procedures. Data collection occurred over a three-year period from May 1, 2010 through September 30, 2012. In 2012 (Year 3), Iowa DNR completed all data collection and analyses and created this final project report. A standard set of abiotic, biotic and landscape metrics were measured at sixteen sites located throughout Iowa's Prairie Pothole Region (Figure 2; Appendix 1).

2010-2012 Shallow Lakes Monitoring Sites

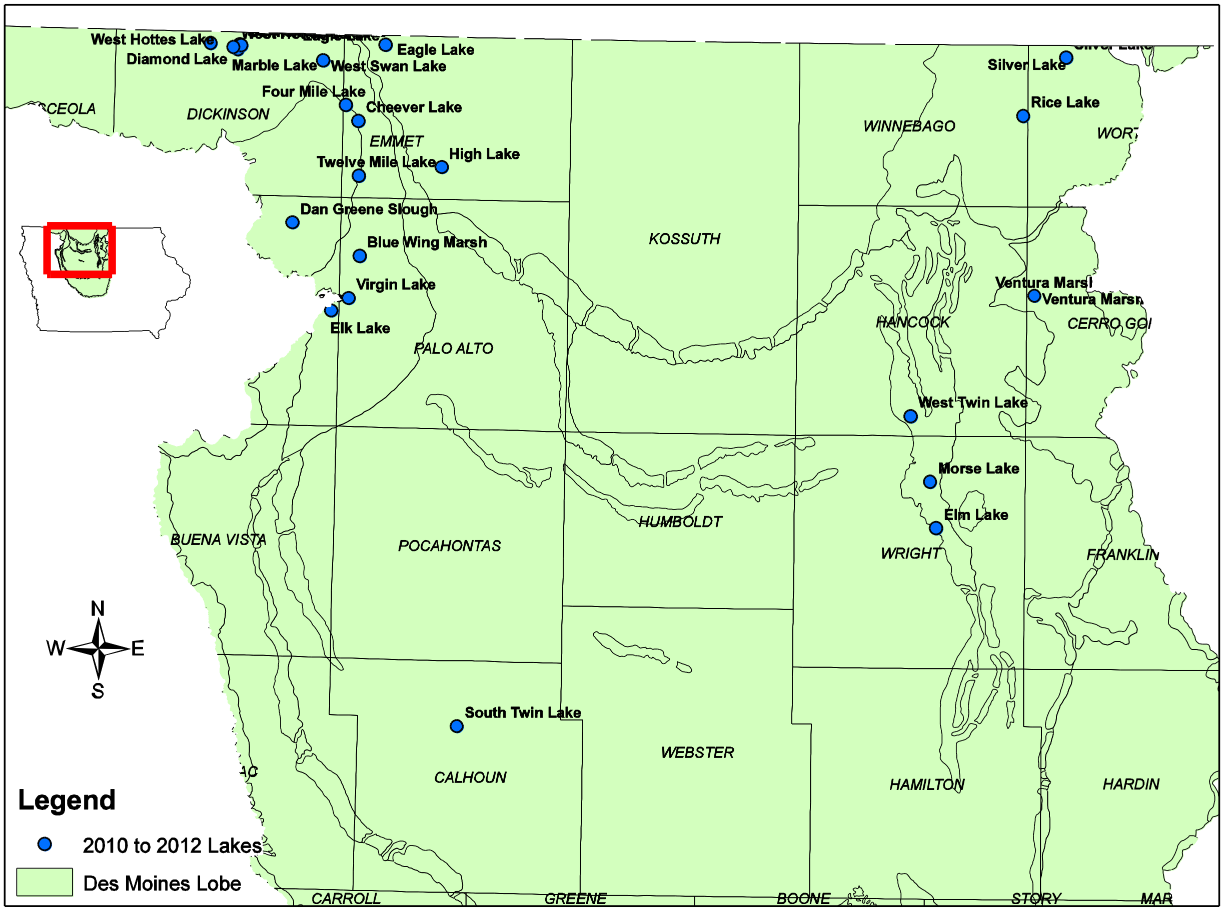


Figure 2. Map of monitored shallow lakes and large wetlands located within Iowa's Prairie Pothole Region.

Chemical Parameters

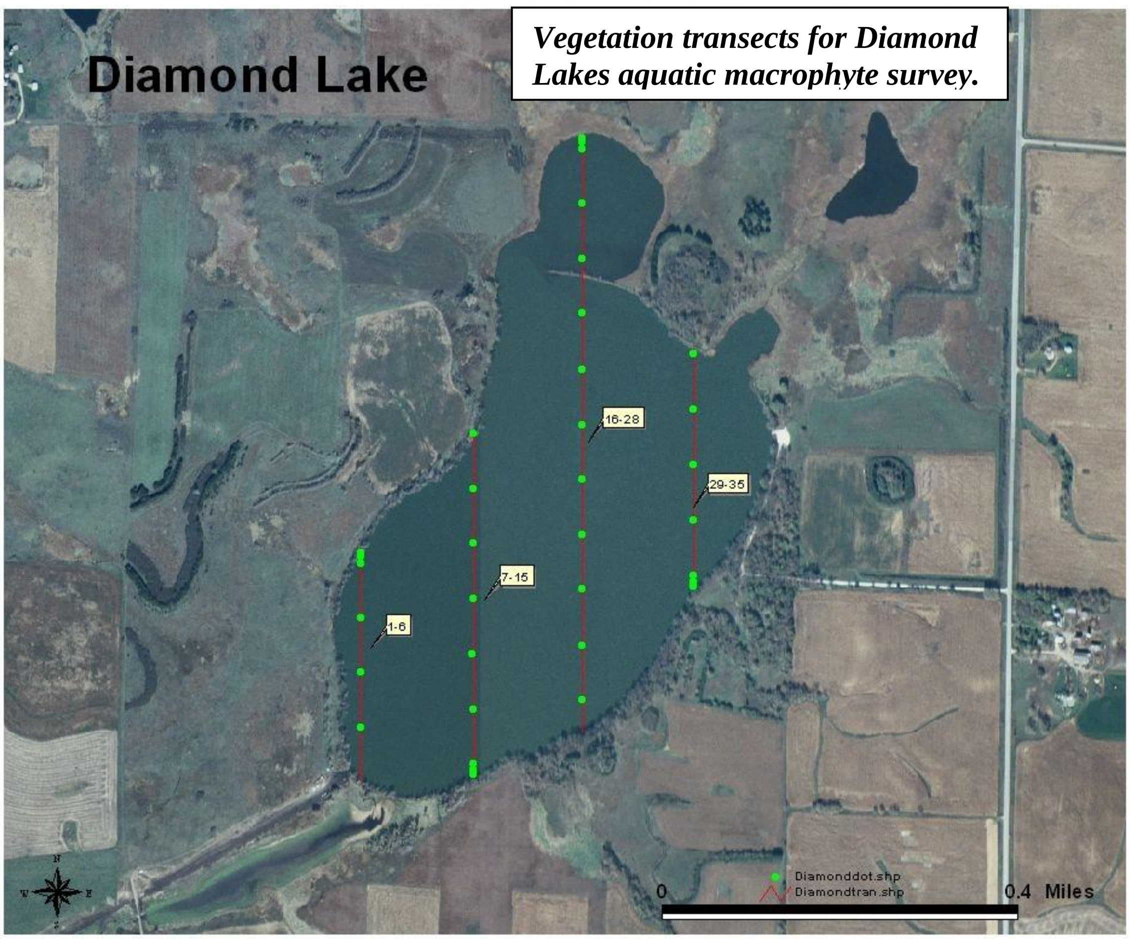
Water chemistry samples were collected at the deepest water zone, and standard sampling procedures were followed. Dissolved oxygen and pH were measured by a multi-paramter probe. All samples were stored in plastic bottles, labeled, and placed into a cooler with ice until they were delivered to the State Hygienic Laboratory (SHL) for further analysis. Total phosphate (P), orthophosphate, total Kjeldahl nitrogen, nitrite + nitrate and ammonia nitrogen (N) were also measured and recorded. Total suspended solids and Chlorophyll-a were analyzed and recorded by the SHL. Water quality parameters were sampled monthly at each site (n = 16) from May through September, 2010-2012.

Physical Parameters

A standard suite of physical data were collected using a multi-parameter probe. The data included water temperature and conductivity. Turbidity and Secchi depth were also measured and recorded. The surrounding land use of each site was assessed using current GIS land cover maps to note public drainage tiles, drainage ditches, bathymetric features, and other relevant physical traits within each shallow lake's watershed. This information will allow managers to pinpoint potential hot-spots for nutrient and sediment inputs.

Biological Parameters

Sampling the biological communities of these systems increases our understanding of the biotic factors that affect or can be affected by changes in water quality and habitat conditions. Aquatic ecosystems can change drastically following changes in water levels (i.e., drawdowns, drought). The biotic communities which were directly affected include aquatic plants, birds, fish, invertebrates and plankton. The eradication of exotic rough fish via periodic drawdowns can help reestablish healthy aquatic plant and invertebrate communities.



During the years of 2010-2012, vegetation and fisheries surveys were conducted at each site in the month of July. Fish were sampled using modified fyke nets and Gee-type minnow traps, while vegetation was sampled along predetermined transects within the sites.

Invertebrate sampling occurred once annually in either April or July using a D-net at one location within each site. Both zooplankton and phytoplankton samples were collected monthly at each site. Zooplankton samples were collected using a Wisconsin plankton net thrown three times for a total sample distance of fifteen meters. The invertebrate and zooplankton samples were preserved with ethanol on site prior to shipment to the laboratory for analysis. The phytoplankton samples were preserved in an opaque container using Lugol's solution.

Field and laboratory data were recorded, analyzed, and archived by the Iowa DNR WMAS. Further analyses and interpretation of this data will be shared among Iowa DNR, DU and US Fish and Wildlife Service staff. The laboratory cost to process collected samples ranged from approximately $2,397/site/year in 2010 to $2,607/site/year in 2012 (Table 1). These are based on contract prices established by the State Hygienic Laboratory (SHL) and were subject to change during the three year project period.

PROJECT PARTNERS

This project was a collaborative effort among the Iowa DNR Wildlife, Fisheries, and Lake Restoration bureaus, Iowa DNR Watershed Monitoring and Assessment Section, and Ducks Unlimited. The WMAS coordinated and performed all field work, data collection and laboratory analyses. The Iowa DNR Wildlife, Fisheries, and Lake Restoration bureaus agreed to provide a minimum of $20,000 cash per year ($60,000 total) in cost-share assistance to help support these efforts.

DU was awarded a <u>$75,000 grant over 3 years </u>($25,000 payable/fiscal year) from the Prairie Pothole Joint Venture (PPJV) to help support and expand the Iowa DNR's Shallow Lakes Monitoring Program. As part of the required 1:1 non-federal match, DU also contribute $16,800 ($16,500 cash and $300 of donated indirects) of matching funds for a total combined non-federal commitment of $76,800 (1.02 to 1 match ratio) over the three year project period (Table 2).

Table 1. Shallow lake monitoring parameters, sampling frequency and annual cost for processing samples collected at each site (*n* = 16) during 2012.

Parameter	Sampling Frequency	Months Sampled	Cost/Sample	Parameter Cost/Site/Year
Lab Analytes				
Chloride	Monthly	May - September	$13.00	$65.00
Ammonia as N	Monthly	May - September		
Total Kjeldahl N	Monthly	May - September	$59.00	$295.00
Nitrate / Nitrite a N	Monthly	May - September		
Ortho Phosphate a P	Monthly	May - September	$26.00	$130.00
Total Phosphorus a P	Monthly	May - September		
Total Dissolved Solids	Monthly	May - September	$13.00	$65.00
Total Suspended Solids	Monthly	May - September	$13.00	$65.00
Total Volatile Susp. Solid	Monthly	May - September	$26.00	$130.00
Chlorophyll-a	Monthly	May - September	$39.00	$195.00
Biological Sampling				
Zooplankton	Monthly	May - September	$83.00	$415.00
Phytoplankton	Monthly	May - September	$83.00	$415.00
Invertebrate	Yearly	Early May/Mid-July	$176.00	$352.00
Fish	Yearly	July	$220.00	$220.00
Vegetation	Yearly	July	$60.00	$60.00
Field Measurements				
Temperature	Monthly	May - September		
Dissolved Oxygen	Monthly	May - September		
pH	Monthly	May - September	$40.00	$200.00
Conductivity	Monthly	May - September		
Secchi Depth / Turbidity	Monthly	May - September		
			Estimated Total Cost/Site/Year	**$2,607.00**

Table 2. Matching partner commitments to monitor and evaluate 16 pre- and post-renovated priority shallow lakes and large wetland complexes located throughout Iowa's Prairie Pothole Region, 2010-2012. (For a detailed budget please refer to the Appendix 1)

Partners	Year 1 (2010)	Year 2 (2011)	Year 3 (2012)	TOTALS
Iowa Department of Natural Resources	$20,000	$20,000	$20,000	$60,000
Ducks Unlimited, Inc. (grantee)	$5,600	$5,600	$5,600	$16,800
U.S. Fish & Wildlife Service (JV Flex Funds)	$25,000	$25,000	$25,000	$75,000
TOTALS	**$50,600**	**$50,600**	**$50,600**	**$151,800**

TASK TIMELINE

Year 1 (2010):
Select sixteen restored and non-restored shallow lakes and large wetland complexes for inclusion in this study (Figure 2; January-March); collect physical, chemical, and biological data (May-Sept.); process collected samples at the State Hygienic Laboratory (May-December); present preliminary findings at partner and scientific meetings (November-December) and submit an interim annual report (November).

Year 2 (2011):
Continue monitoring sixteen priority shallow lakes and large wetland complexes (May-Sept.); process collected samples at the State Hygienic Laboratory (May-December); present preliminary findings at partner and scientific meetings (November-December) and submit interim annual report (November).

Year 3 (2012):
Continue monitoring sixteen priority shallow lakes and large wetland complexes (May-Sept.); process collected samples at the State Hygienic Laboratory (May-December) and present preliminary findings at partner and scientific meetings; submit final report within 90 days of the project completion date (9/30/12).

RESTORED & NON-RESTORED SITES

For the purpose of this report, restored sites were those sites where restoration work was completed prior to starting this three year study, with the exception of one site (Dan Green Slough) that had been restored prior to 2010, but did not refill to levels suitable for sampling until 2011. The other three restored sites were Big Wall Lake, Diamond Lake, and Four Mile Lake. Cheever Lake, a non-restored shallow lake, had been and will continue to be used in this report, as a reference lake. Cheever Lake had some accessibility issues (i.e., cattails blocking access) over the three year study period and sampling data from these three years is very limited. Non-restored sites were those sites not having undergone any restoration work, or having restoration work started, but not fully completed during the three year project period. These include all remaining sites listed in Appendix 1.

OUTCOMES & BENEFITS

Iowa's Shallow Lake Monitoring Program embodies a true partnership among conservation groups, public agencies, local communities and individual supporters. This partnership is focused on providing science-based information to help guide future conservation planning and management decisions. The results of this project will provide objective criteria for identifying specific biotic and abiotic factors that influence the water quality and ecological condition of Iowa's shallow lakes and large wetland complexes.

Results of this three year monitoring study will help resource agencies and partners develop strategic science-based habitat conservation objectives and management strategies that benefit waterfowl and other high priority migratory bird species. By partnering with the PPJV, the Iowa DNR hopes to improve water quality, enhance critical migratory bird habitat, and provide additional public recreational, ecological, and cultural benefits for all Iowans. Support from the PPJV will help us achieve these important objectives and advance the goals of the PPJV's Implementation Plan and Iowa's *Living Lakes* Initiative.

Three basic criteria were used to evaluate the success of this project and help quantify the overall environmental benefits:

- Compare and demonstrate measurable improvements in physical (e.g., increased Secchi depths), chemical (e.g., reduced nitrate levels), and biological (e.g., increased submerged plant growth, significant reduction in rough fish populations) conditions of restored versus non-restored shallow lakes and large wetland complexes.

- Generate further public and financial support to help strengthen and expand Iowa's Shallow Lakes Restoration Program.

- Propose the adoption of monitoring standards and objective assessment criteria by resource agencies in Iowa and potentially other Midwestern states.

By monitoring a standard set of physical, biological and chemical parameters at sixteen restored and non-restored sites, the Iowa DNR will be able to: (1) establish baseline shallow lake conditions at a regional scale; (2) identify site-specific impairments; (3) evaluate the likelihood of future restoration measures and assess temporal changes and improvements in habitat conditions. Finally, the results of this project provide valuable information and help illustrate the success of this program.

RESULTS

Chemical Data – (In all graphs, restored sites are blue, red sites are non-restored, and the reference site is teal colored unless otherwise noted)

Tropic state index (TSI) values for Chlorophyll-a at restored sites were 68, 57, and 66 for 2010, 2011, and 2012 respectively. No data was available for the Dan Green Slough site in 2010 due to restoration work. TSI values for Chlorophyll-a at non-restored sites were 76, 76, and 79 for 2010, 2011, and 2012 respectively (Figure 3). No data was available at Rice Lake and Twelve Mile Lake in 2010, High Lake in 2011, and Silver Lake and Virgin Lake in 2012 due to the changes in site selection from year to year.

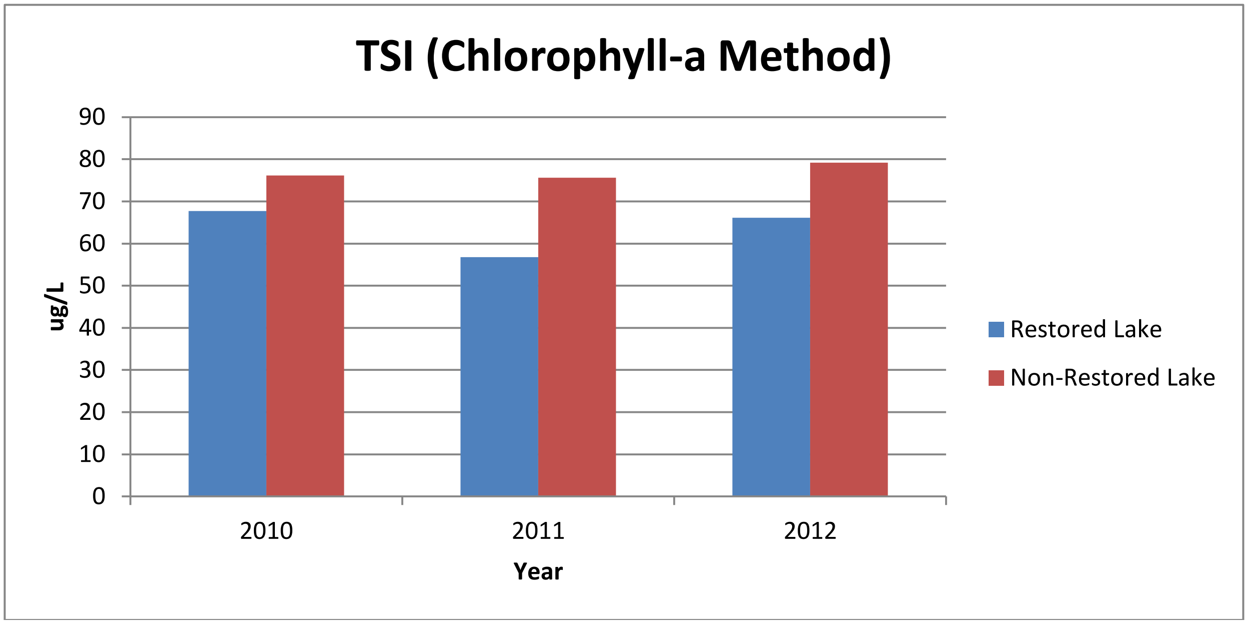


Figure 3. TSI for restored and non-restored sites using the Chlorophyll-a method 2010 to 2012.

Chlorophyll-a monthly average values at restored sites from 2010 to 2012 ranged from 9.47 ug/L in May to 63.71 ug/L in September (Figure 4). June 2012 had the lowest monthly Chlorophyll-a result at 3.75 ug/L while the September 2012 reading of 117.50 ug/L was the highest for restored lakes. Chlorophyll-a monthly average values at non-restored sites ranged from 91.68 ug/L in May to 171.72 ug/L in September between 2010 and 2012. May 2011 had the lowest monthly reading of 41.73 ug/L while September 2012 had the highest reading of 226.70 ug/L. The 2012 season had the highest average Chlorophyll-a reading of all years across all months (181.46 ug/L) while 2010 had the lowest reading of all years across all months (109.98 ug/L).

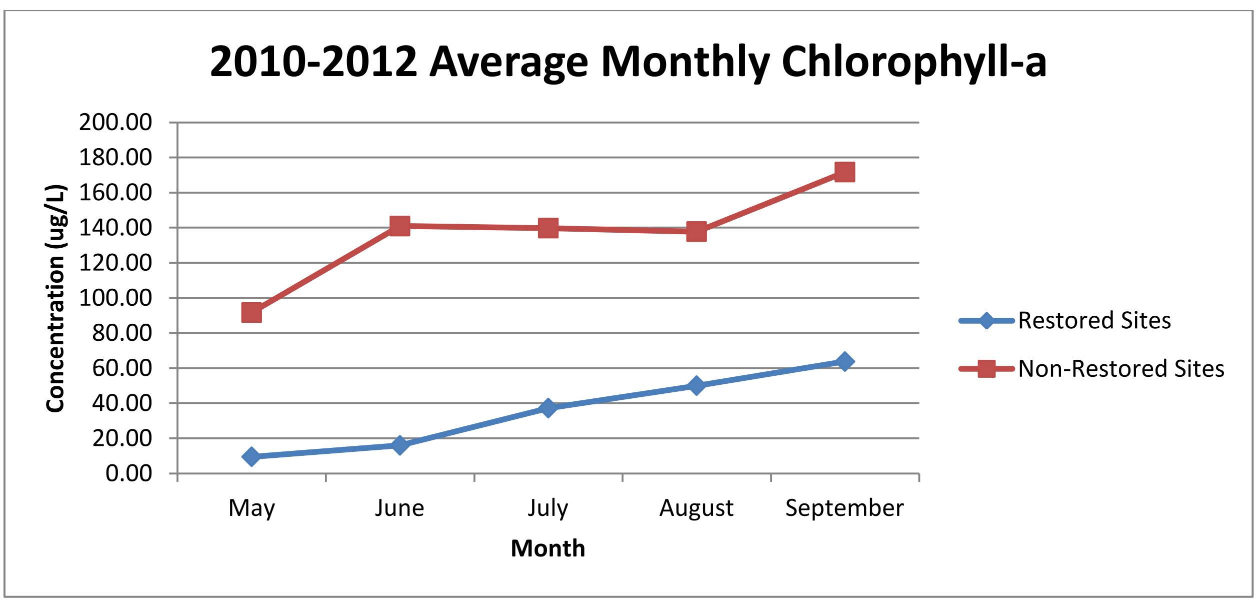


Figure 4. Average monthly Chlorophyll-a for restored and non-restored sites 2010 to 2012.

Total P monthly average values at restored sites from 2010 to 2012 ranged from 0.17 mg/L in May to 0.22 mg/L in July. May and July 2011 had the lowest monthly Total P reading at 0.12 mg/L while the September 2012 reading of 0.31 mg/L was the highest for restored lakes (Figure 5). Total P monthly average values at non-restored sites ranged from 0.17 mg/L in May to 0.37 mg/L in September between 2010 and 2012. May 2010 and 2011 had the lowest monthly reading of 0.11 mg/L while September 2012 had the highest reading of 0.50 mg/L (Figure 6). The 2012 season had the highest average Total P reading of all years across all months (0.40 mg/L) while 2010 had the lowest reading of all years across all months (0.18 mg/L), for non-restored sites.

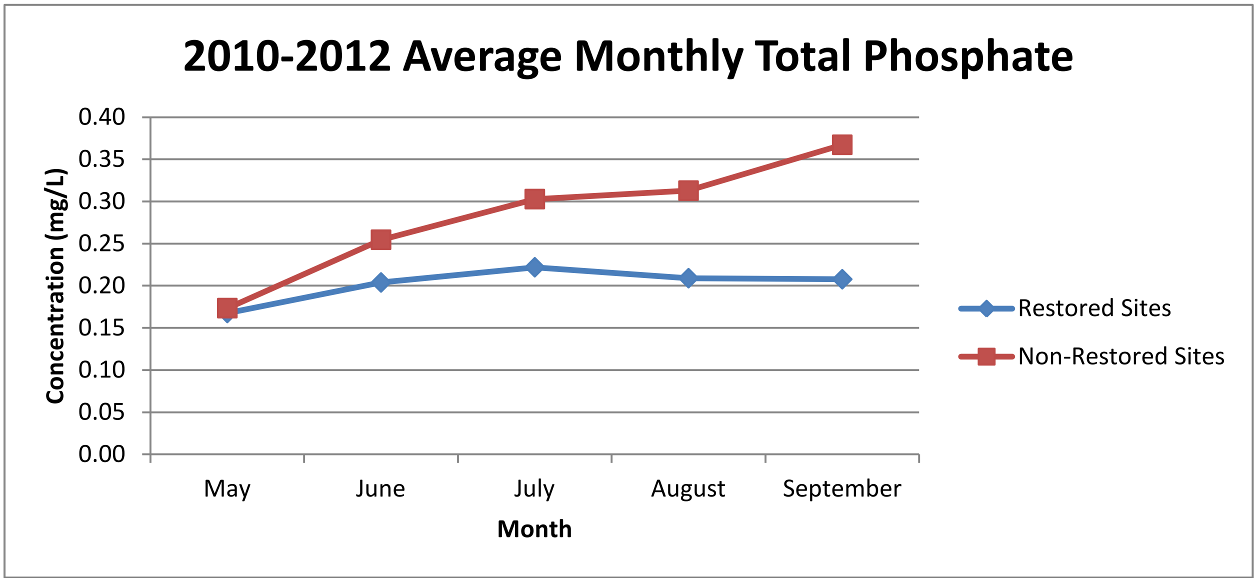


Figure 5. Average monthly Total P for restored and non-restored sites 2010 to 2012.

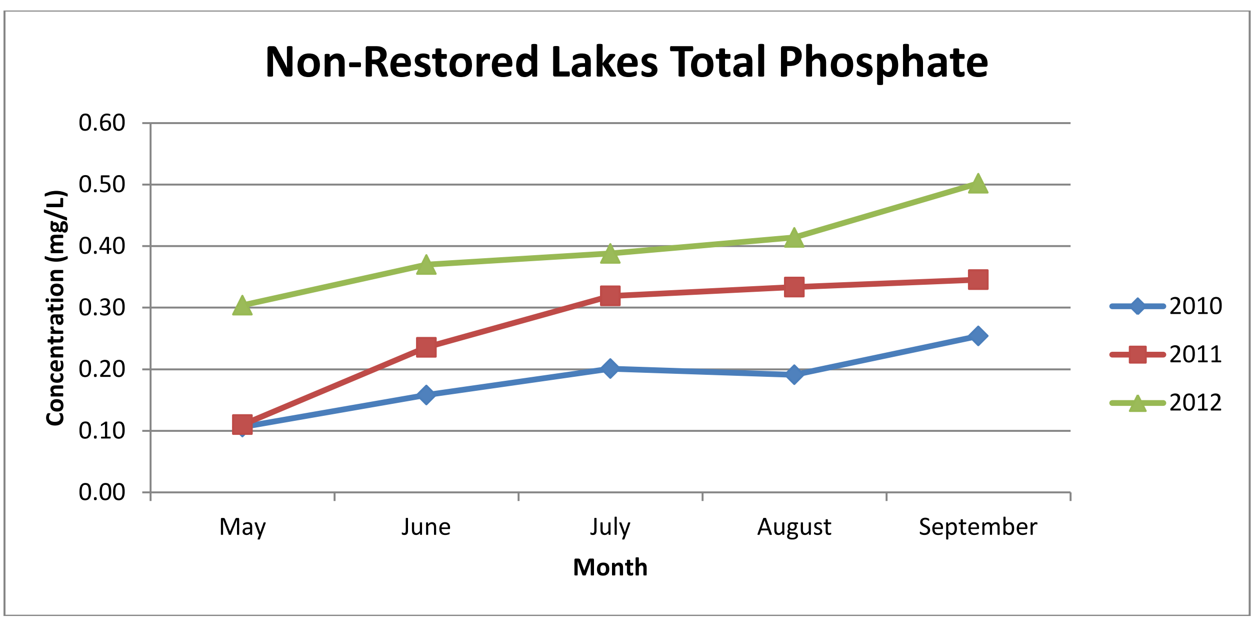


Figure 6. Non-restored sites Total P concentration for 2010 to 2012.

Total suspended solids (TSS) monthly average values at restored sites from 2010 to 2012 ranged from 3.04 mg/L in May to 14.96 mg/L in September. June 2011 had the lowest monthly TSS reading at 1.63 mg/L while the September 2012 reading of 34.13 mg/L was the highest for restored lakes (Figure 7). TSS monthly average values at non-restored sites ranged from 38.59 mg/L in May to 102.34 mg/L in September between 2010 and 2012. May 2011 had the lowest monthly reading of 23.00 mg/L while September 2012 had the highest reading of 166.40 mg/L. The 2012 season had the highest average Total P reading of all years across all months (100.94 mg/L) while 2010 had the lowest reading of all years across all months (45.56 mg/L), for non-restored sites.

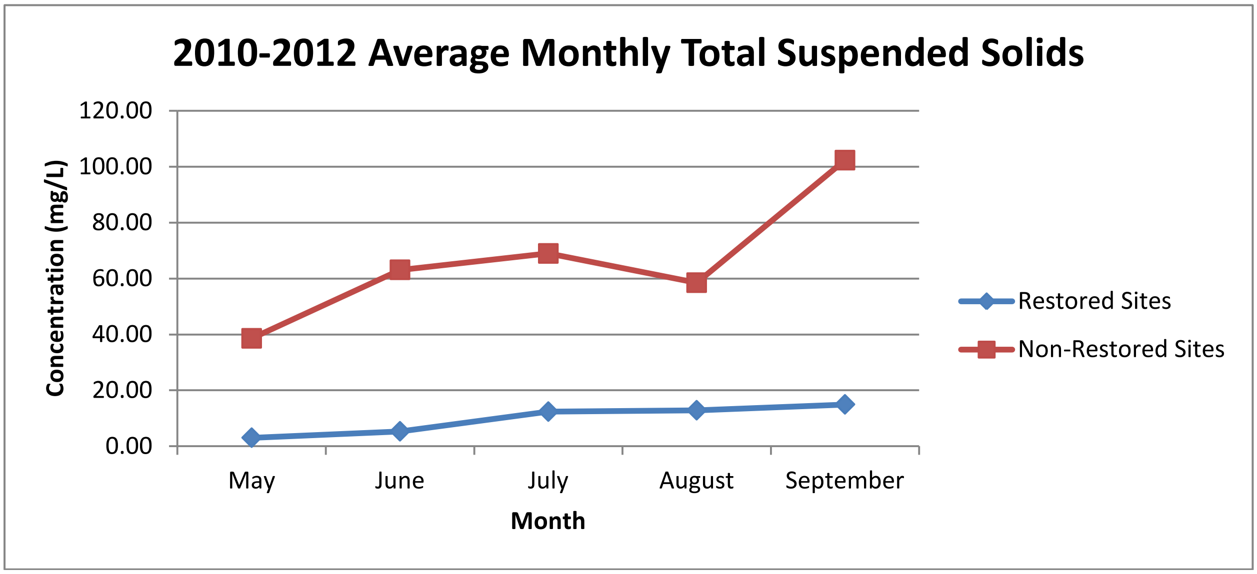


Figure 7. Average monthly TSS for restored and non-restored sites 2010 to 2012.

Ammonia-N monthly average values at restored sites from 2010 to 2012 ranged from 0.03 mg/L during May, June, and July to 0.18 mg/L in September. All months, but 6 months monitored, had the lowest monthly Ammonia-N reading at 0.03 mg/L while the September 2012 reading of 0.41 mg/L was the highest for restored lakes (Figure 8). Ammonia-N monthly average values at non-restored sites ranged from 0.04 mg/L in July and August to 0.18 mg/L in June between 2010 and 2012. July 2010 and 2012 and August 2011 had the lowest monthly reading of 0.03 mg/L while June 2010 had the highest reading of 0.29 mg/L. The 2010 season had the highest average Ammonia-N reading of all years across all months (0.14 mg/L) while 2012 had the lowest reading of all years across all months (0.06 mg/L), for non-restored sites.

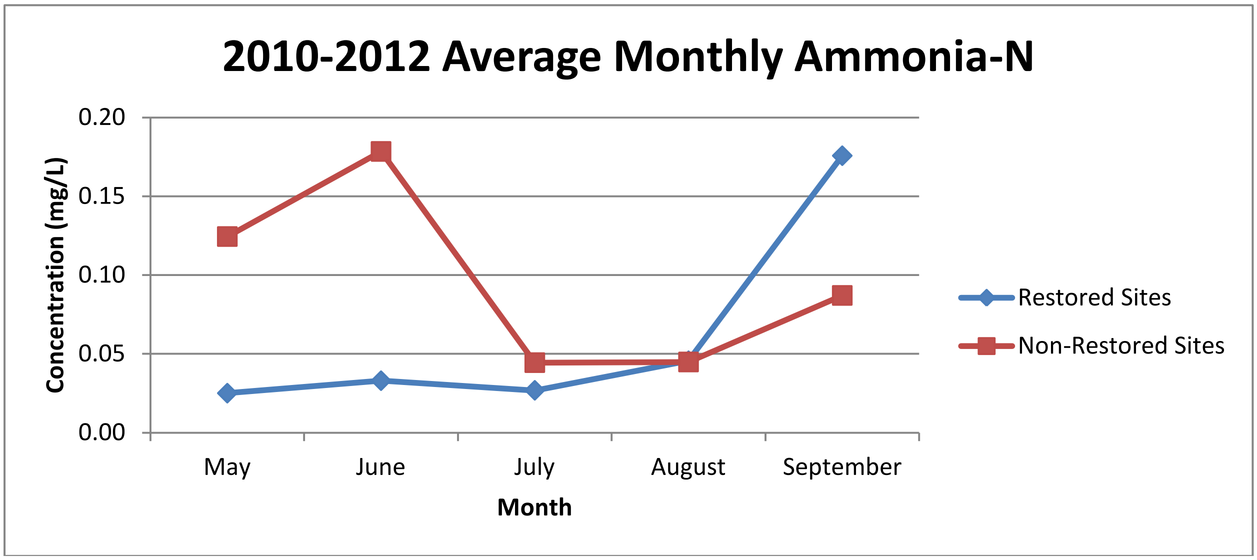


Figure 8. Average monthly Ammonia-N for restored and non-restored sites 2010 to 2012.

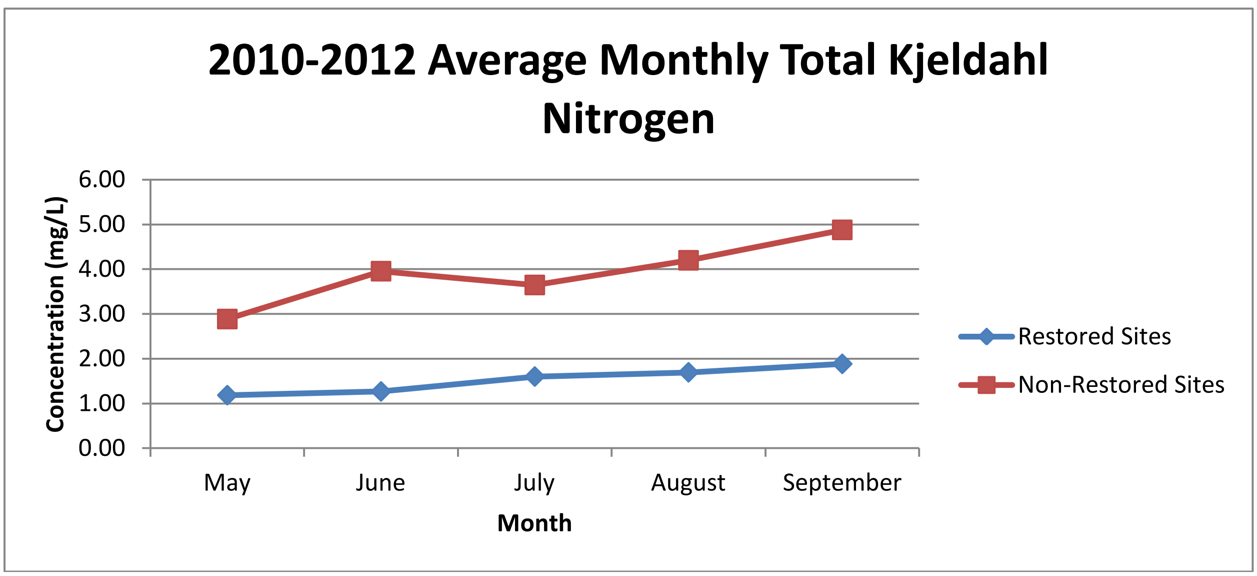


Figure 9. Average monthly TKN for restored and non-restored sites 2010 to 2012.

Total Kjeldahl Nitrogen (TKN) monthly average values at restored sites from 2010 to 2012 ranged from 1.18 mg/L in May to 1.88 mg/L in September. July 2011 had the lowest monthly TKN reading at 0.68 mg/L while the September 2012 reading of 2.60 mg/L was the highest for restored lakes (Figure 9). TKN monthly average values at non-restored sites ranged from 2.88 mg/L in May to 4.88 mg/L in September between 2010 and 2012. May 2011 had the lowest monthly reading of 1.95 mg/L while June 2012 had the highest reading of 5.71 mg/L. The 2012 season had the highest average TKN reading of all years across all months (5.26 mg/L) while 2010 had the lowest reading of all years across all months (3.12 mg/L), for non-restored sites.

Orthophosphate monthly average values at restored sites from 2010 to 2012 ranged from 0.06 mg/L in September to 0.14 mg/L in May. August and September 2012 had the lowest monthly Orthophosphate reading at 0.02 mg/L while the May 2010 reading of 0.25 mg/L was the highest for restored lakes (Figure 10). Orthophosphate monthly average values at non-restored sites ranged from 0.01 mg/L in May to 0.08 mg/L in August between 2010 and 2012. May 2010, 2011, and 2012 had the lowest monthly reading of 0.01 mg/L while August 2011 had the highest reading of 0.11 mg/L. The 2011 season had the highest average Orthophosphate reading of all years across all months (0.06 mg/L) while 2010 had the lowest reading of all years across all months (0.02 mg/L), for non-restored sites.

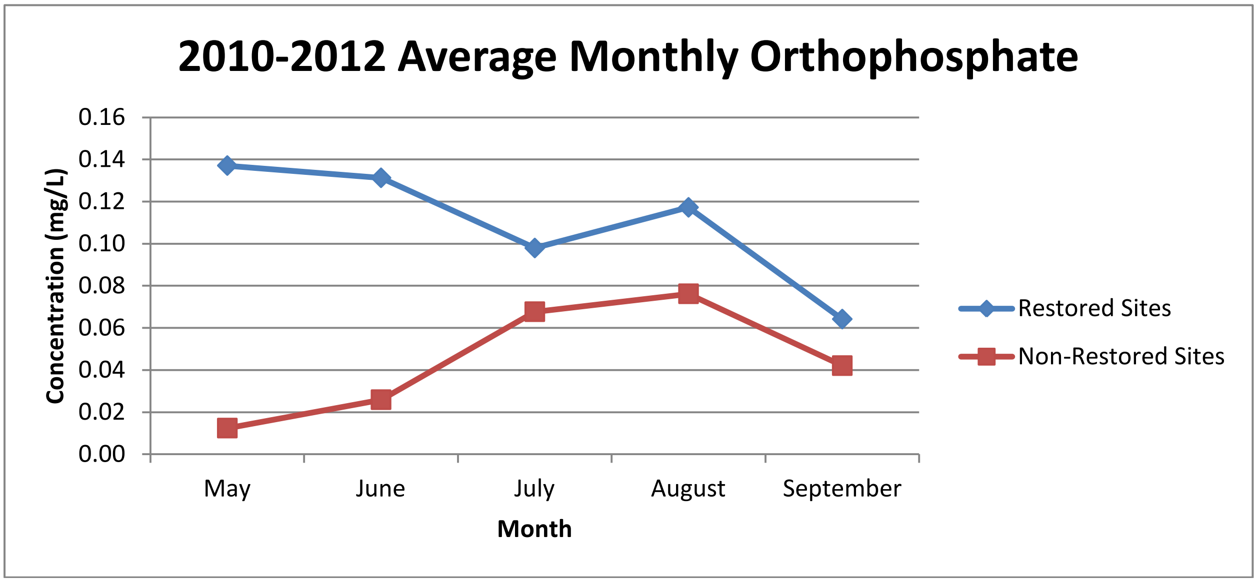


Figure 10. Average monthly Orthophosphate for restored and non-restored sites 2010 to 2012.

Physical Data

The average Secchi depth in centimeters (cm) at restored lakes was 73.78, 82.93, and 67.00 for 2010, 2011, and 2012 respectively (Appendix 2). Secchi depth ranged from the lowest reading of 37.25 cm in August 2012 to the highest reading of 98.75 cm in May of 2012. When all years are averaged June had the highest Secchi reading of 91.14 cm and August had the lowest reading of 58.23 cm. Average Secchi depth, in centimeters, at non-restored lakes was 35.26, 35.38, and 21.12 for 2010, 2011, and 2012 respectively. The average Secchi depth at non-restored sites ranged from the lowest reading of 11.10 cm in September 2012 to the highest reading of 56.50 cm in May of 2010. When all years are averaged May had the highest Secchi reading of 45.43 cm and September had the lowest reading of 18.81 cm (Figure 11 & 12).

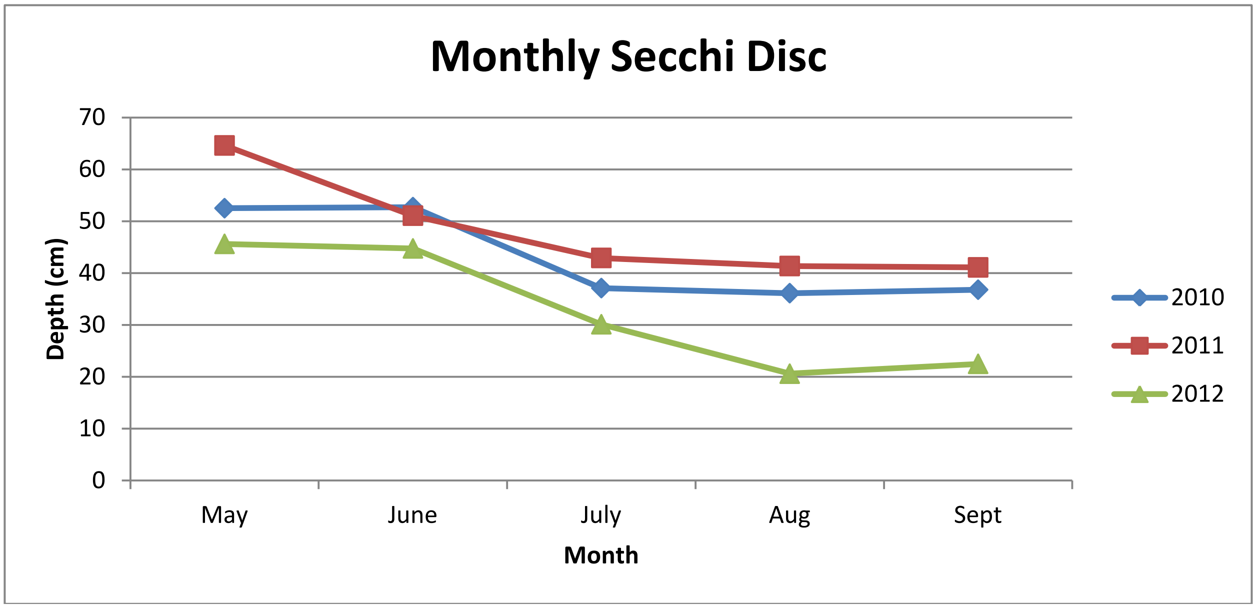


Figure 11. Monthly Secchi disc depth for all sites from 2010 to 2012.

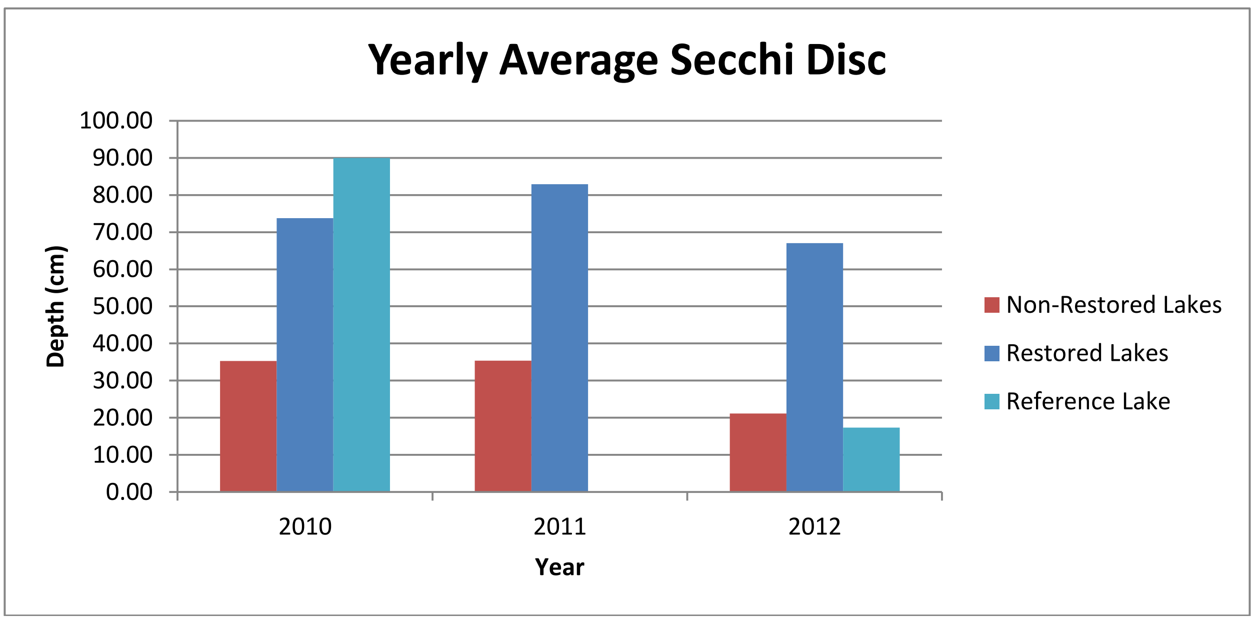


Figure 12. Yearly average Secchi disc depth from 2010 to 2012.

Turbidity (NTU units) average at restored lakes was 3.44, 3.55, and 6.88 for 2010, 2011, and 2012 respectively. Turbidity ranged from the lowest reading of 1.82 NTU in June 2011 to the highest reading of 17.22 NTU in September of 2012. When all years are averaged September had the highest Turbidity reading of 8.06 NTU and May had the lowest reading of 2.32 NTU. Average Turbidity, in NTU's, at non-restored lakes was 38.58, 60.88, and 104.63 for 2010, 2011, and 2012 respectively (Appendix 2; Figure 13). Non-restored sites Turbidity ranged from the lowest reading of 19.55 NTU in May 2010 to the highest reading of 153.79 NTU in September of 2012. When all years are averaged September had the highest Turbidity reading of 96.22 NTU and May had the lowest reading of 44.21 NTU.

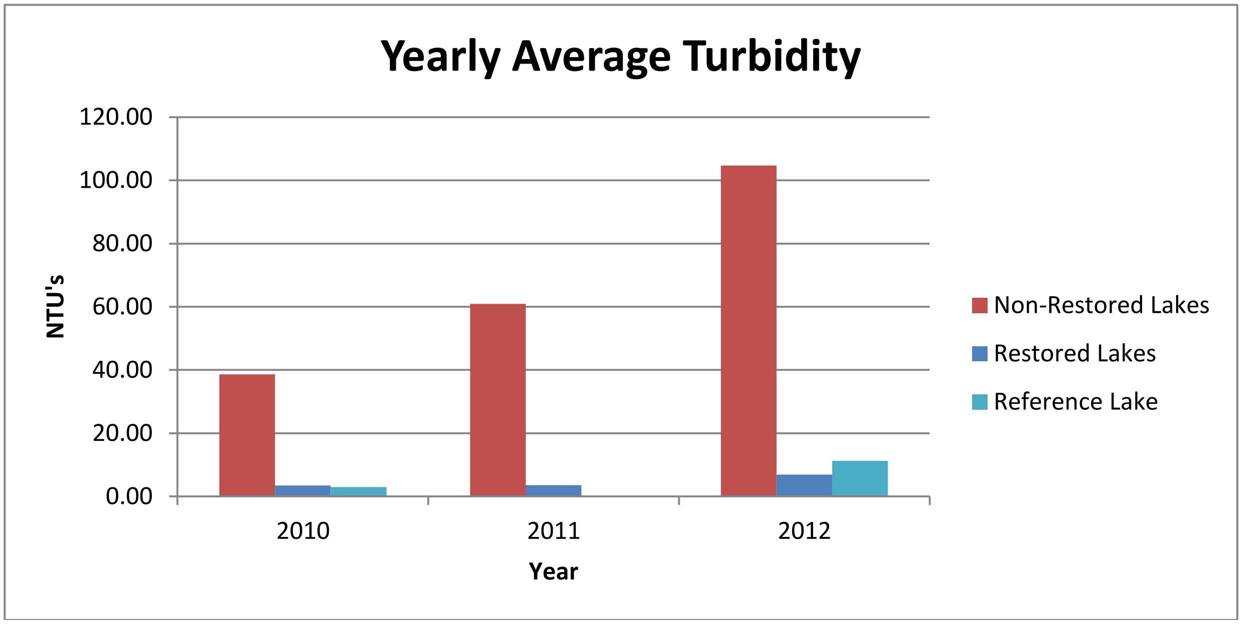


Figure 13. Yearly average Turbidity from 2010 to 2012 for reference, restored, and non-restored sites.

Biological

Fish Survey

Ten sites were surveyed for fisheries information in 2010, six sites were surveyed in 2011, and five sites were surveyed in 2012 for a total of 21 individual site visits. Carps and Minnows (Cyprinidae) dominated shallow lakes ecosystems, comprising 46% of the overall average population (Figure 14). Cyprinidae species from most abundant to least abundant were: Brassy Minnow (*Hybognathus hankinsoni*), Fathead Minnow (*Pimephales pomelas*), Bullhead Minnow (*Pimephales vigilax*), Common Carp (*Cyprinus carpio*), and Golden Shiner (*Notemigonus crysoleucas*).

Catfish (Ictaluridae) made up 35% of the average overall population followed next by Sunfish (Centrarchidae - 13%) and Perch (Percidae - 4%). Ictaluridae species from most abundant to least abundant were: Black Bullhead (*Ameiurus melas*), Yellow Bullhead (*Ameiurus natalis*), and Channel Catfish (*Ictalurus punctatus*) . Centrarchidae species from most abundant to least abundant were: Orange Spotted Sunfish (*Lepomis humilis*), Bluegill (*Lepomis macrochirus*), Green Sunfish (*Lepomis auritus*), Black Crappie (*Pomoxis nigromaculatus*), Pumpkinseed (*Lepomis gibbosus*), and White Crappie (*Pomoxis annularis*). Percidae species from most abundant to least abundant were: Yellow Perch (*Perca flavescens*), Walleye (*Sander vitreus*), and Johnny Darter (*Etheostoma nigrum*).

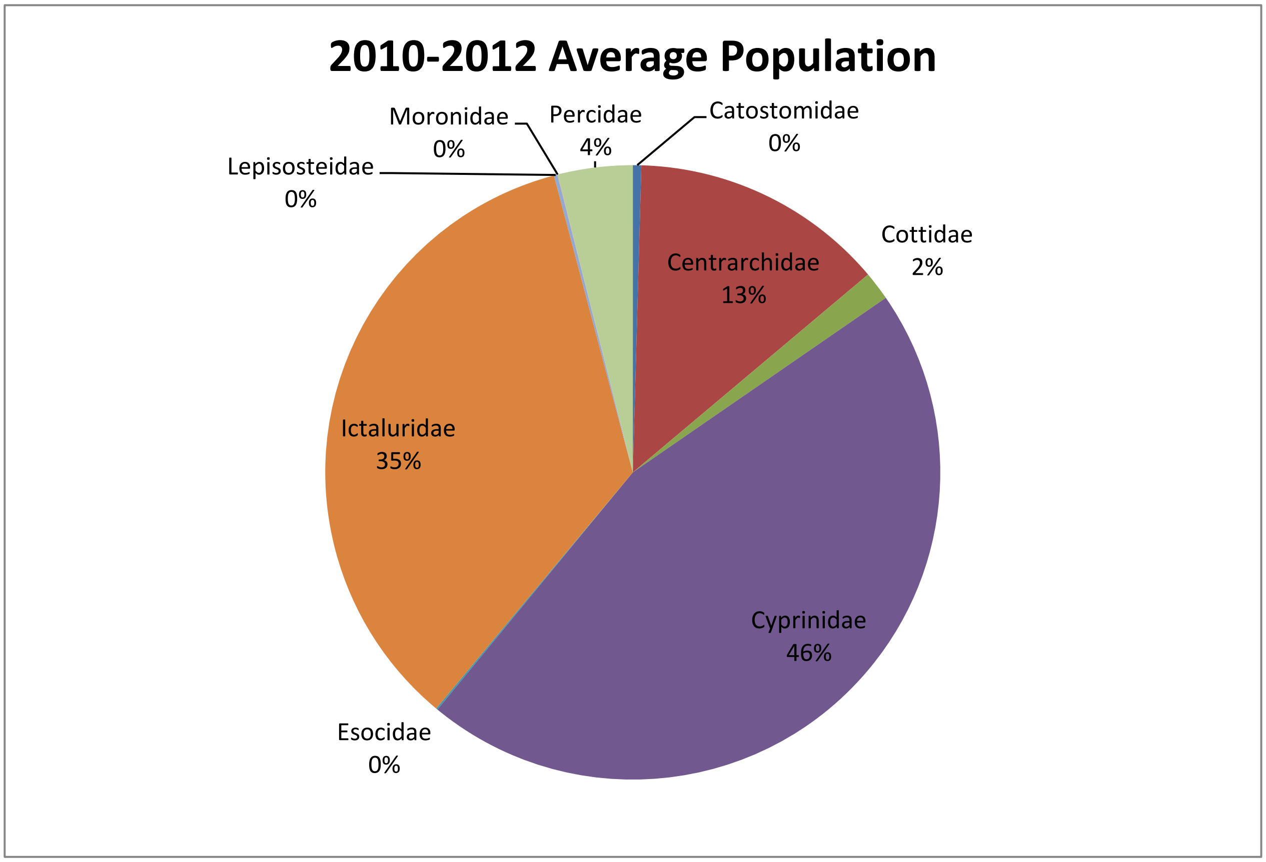


Figure 14. Average fish population by order for all sites (2010 to 2012).

Family Sculpins (Cottidae) was represented by the Three-Spined Stickleback (*Gasterosteus aculeatus*). The following families (and species) were represented in the average population across all lakes by < 25 individuals per family: Catostomidae (Bigmouth Buffalo; *Ictiobus cyprinellus* & White Sucker; *Catostomus commersonii*), Esocidae (Northern Pike; *Esox lucius*), Lepososteidae (Shortnose Gar; *Lepisosteus platostomus*), and Moronidae (White Bass; *Morone chrysops*).

Restored sites average fish populations were dominated by Cottidae (53%), followed by Cyprinidae (31%), Centrarchidae (9%), Ictaluridae (6%), Percidae (1%), and Pike (Esocidae) (Figure 15). The Cottidae family was represented by the Three-Spine Stickleback and Stickleback Spp. (field staff identification to stickleback species and no further identification followed). The Cyprinidae family was represented by only the Fathead Minnow. The Centrarchidae family was represented by the Green Sunfish and Bluegill by most abundant. The Ictaluridae family was comprised of 30 Black Bullhead captured in 2011 (27 specimens from Big Wall Lake and 3 specimens from Dan Green Slough). Percidae was comprised of 4 Yellow Perch caught in 2010 at Diamond Lake. One Northern Pike of the Esocidae family was captured in 2010, also at Diamond Lake.

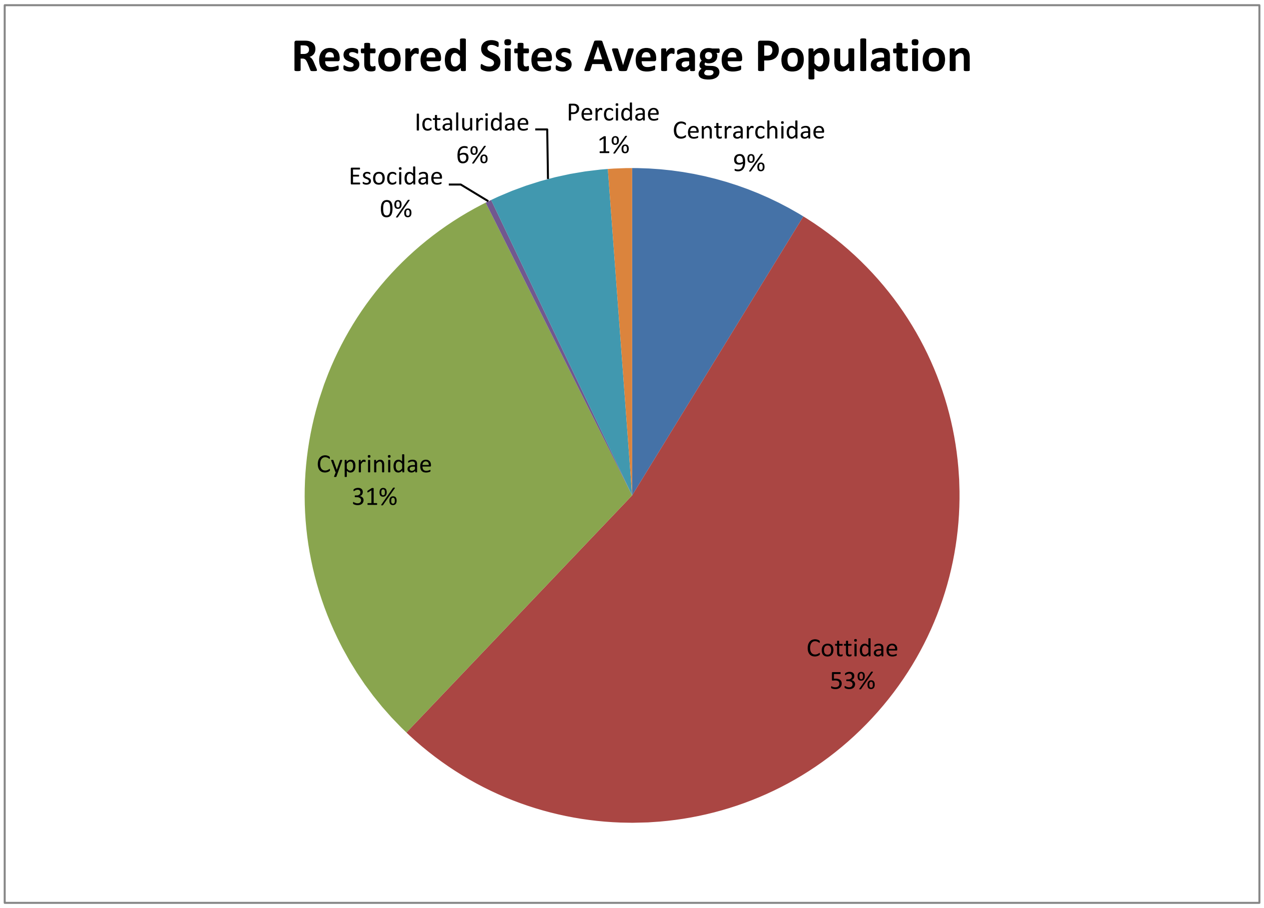


Figure 15. Fish population percentage from 2010 to 2012 by order for restored sites.

Non-restored sites average fish populations were dominated by Cyprinidae (41%), followed by Ictaluridae (39%), Centrarchidae (8%), Percidae (7%), Catostomidae (2%), Lepisosteidae (2%), and Moronidae (Figure 16). The Cyprinidae family was represented by the Brassy Minnow, Fathead Minnow, Bullhead Minnow, Common Carp, Golden Shiner, Spotfin Shiner (*Cyprinella spiloptera*), and Bluntnose Minnow (*Pimephales notatus*), by most abundant. The Ictaluridae family was represented by the Black Bullhead, Yellow Bullhead, Channel Catfish, and Brown Bullhead (*Ameiurus nebulosus*), by most abundant. The Centrarchidae family was represented by Orange Spotted Sunfish, Blugill, Black Crappie, Green Sunfish, Pumpkinseed, White Crappie, and Rock Bass (*Ambloplites rupestris*), by most abundant. The Percidae family was comprised of Yellow Perch, Walleye, and Johnny Darter, by most abundant. Catostomidae was comprised of fifteen White Suckers all captured in Elk Lake in 2012 and thirteen Bigmouth Buffalo captured (three specimens in 2010 and ten specimens in 2012). Lepisosteidae was comprised of sixteen Shortnose Gar (ten specimens in 2010 and six in 2012; all of which were captured in West Hottes Lake with the exception of one specimen in 2010 from neighboring Marble Lake). One White Bass (47 cm total length; 18 inches) of the Moronidae family was captured in 2012 at Rice Lake.

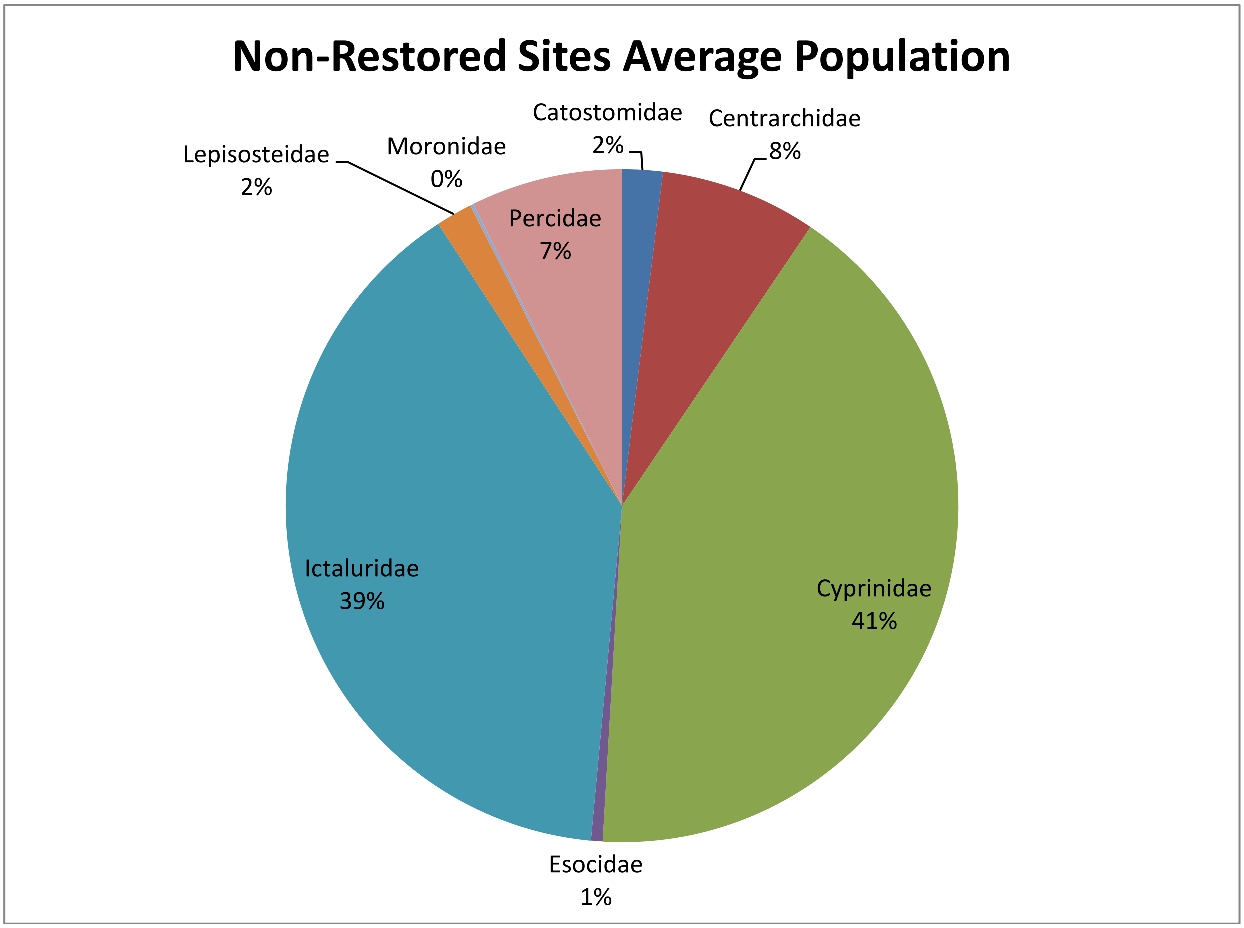


Figure 16. Fish population percentage from 2010 to 2012 by order for non-restored sites.

As a side note for fish netting, we also captured painted turtles (*Chrysemys picta*) (191 specimens), snapping turtles (*Chelydra serpentine*) (24 specimens), and one softshell species turtle from 2010 to 2012.

Aquatic Invertebrate Survey

Taxa richness from 2010 to 2012 for restored sites was fifteen, while non-restored sites taxa richness was thirteen. Taxa richness was greatest at restored Big Wall Lake (fifteen) while Elm Lake had one individual present (Figure 17). Restored sites taxa richness ranged from four species (Dan Green Slough) to fifteen taxa at Big Wall Lake. Non-restored taxa richness ranged from one taxa at Elm Lake to eleven taxa at Marble Lake.

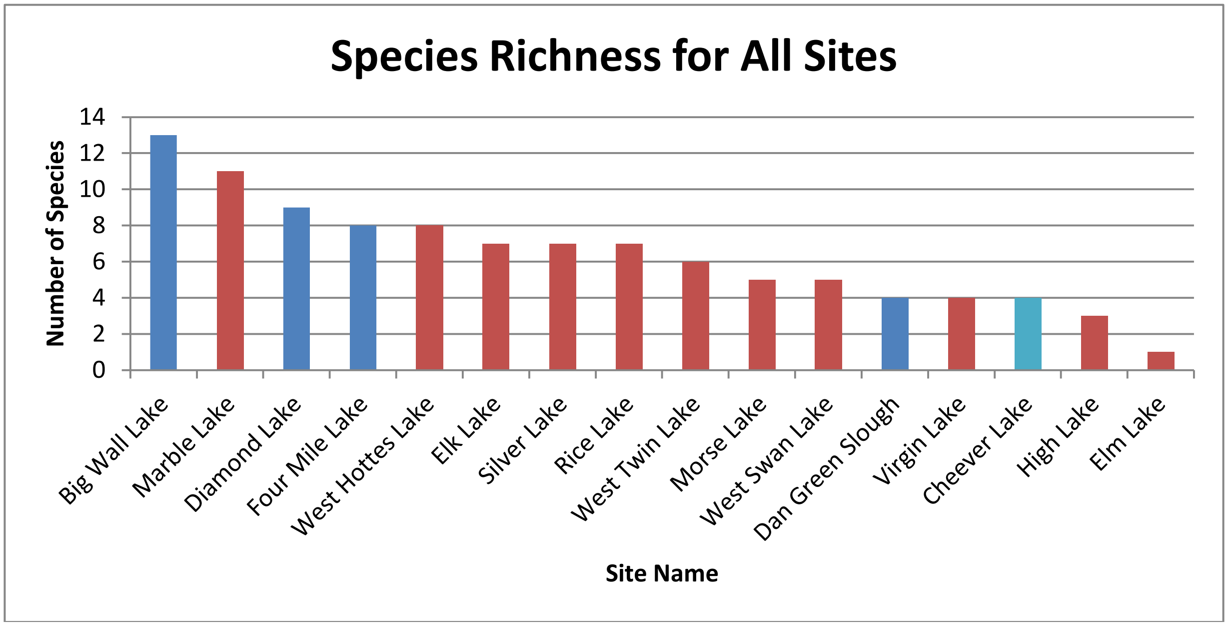


Figure 17. Aquatic invertebrate species richness for all sites from 2010 to 2012.

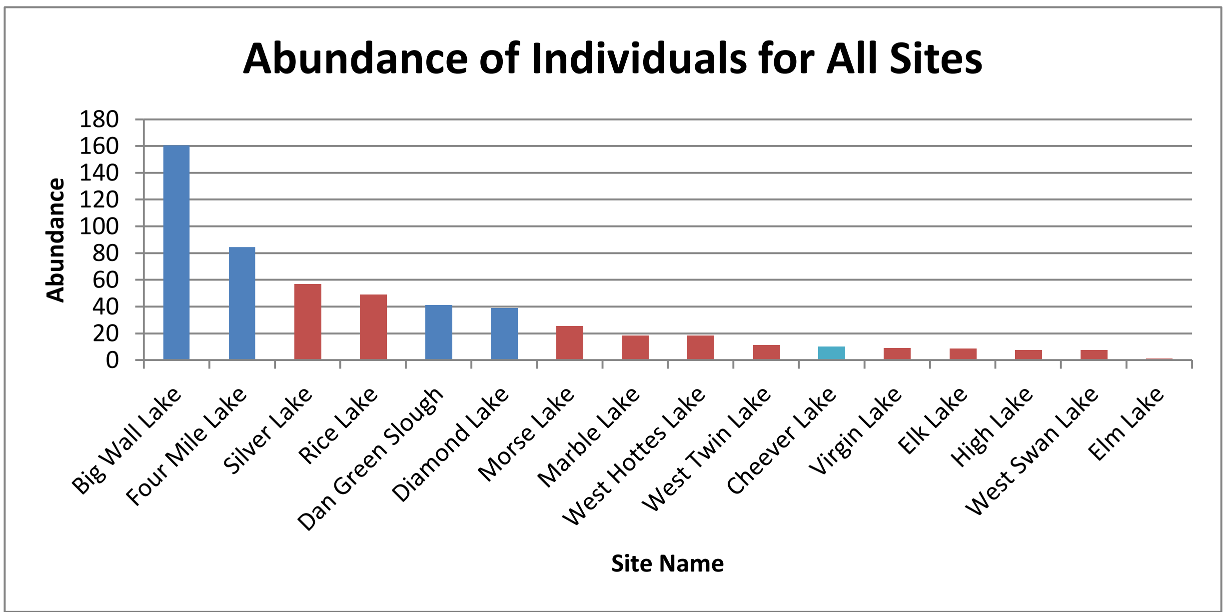


Figure 18. Abundance of individual invertebrates by site for all sites from 2010 to 2012.

Average abundance of individuals per restored site was 96 individuals, while non-restored sites averaged 16 individuals. Average invertebrate abundance ranged from 160.5 at Big Wall Lake to 1 invertebrate for Elm Lake from 2010 to 2012 (Figure 18). Restored sites average abundance ranged from 39 individuals (Diamond Lake) to 160.5 individuals at Big Wall Lake. Non-restored sites average abundance ranged from 1 individual (Elm Lake) to 57 individuals at Silver Lake.

Restored sites versus non-restored sites for 2010 and 2012 depict a large discrepancy in average abundance and invertebrate taxa (Figure 19). Restored sites had a Gastropoda average abundance of 20.5 individuals per site versus non-restored sites abundance of 0.2 individuals per site. Restored sites also had a Hemiptera average abundance of 19.8 individuals per site versus a non-restored site abundance of 4.9 individuals per site. Diptera average abundance was 16.4 individuals per site at restored sites and 3.8 individuals per site at non-restored sites. Odonata average abundance was 11.4 individuals per site at restored sites and 0.1 individuals per site at non-restored sites. Trichoptera average abundance was 1.4 individuals per site at non-restored sites and 0.3 individuals per site at restored sites. Oligochaeta average abundance at restored sites was 4.8 individuals per site while non-restored site abundance was 0.1 individuals per site. Isopoda were not found in non-restored sites, but were found with an average abundance of 2.85 individuals per site at restored sites.

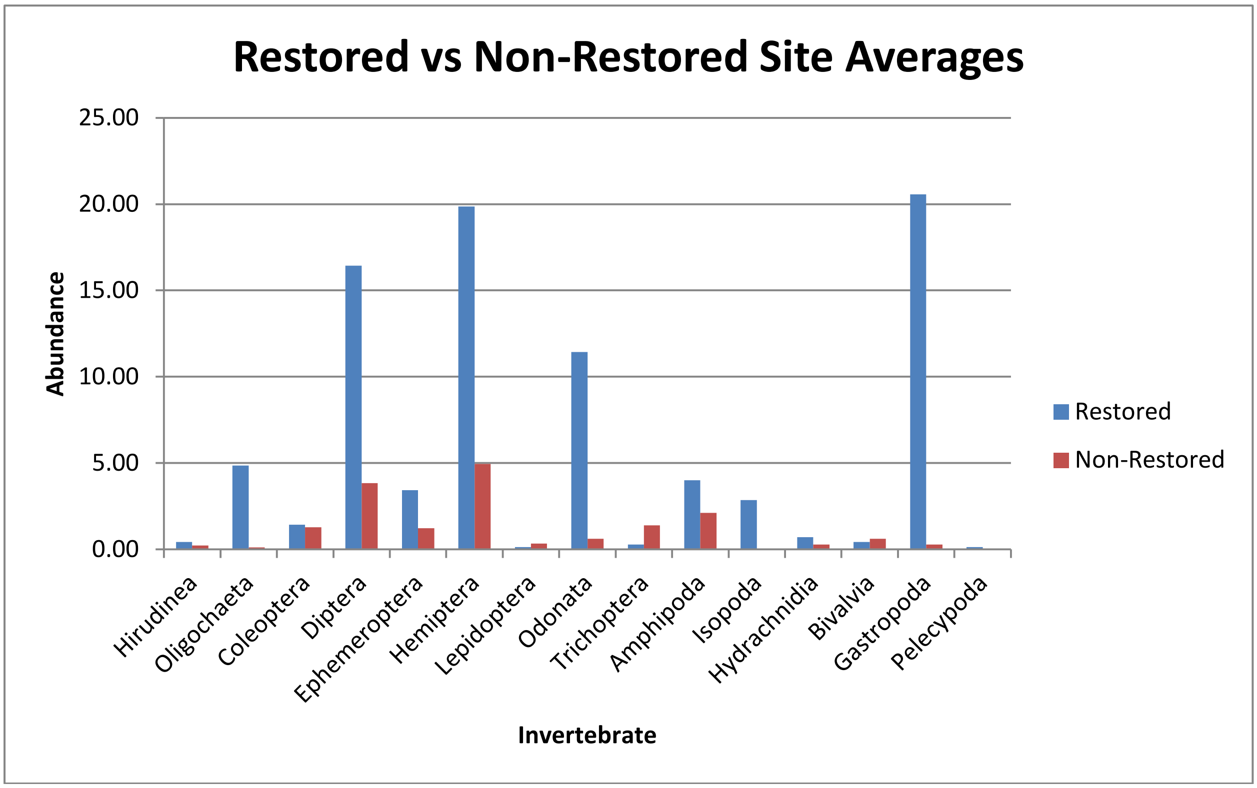
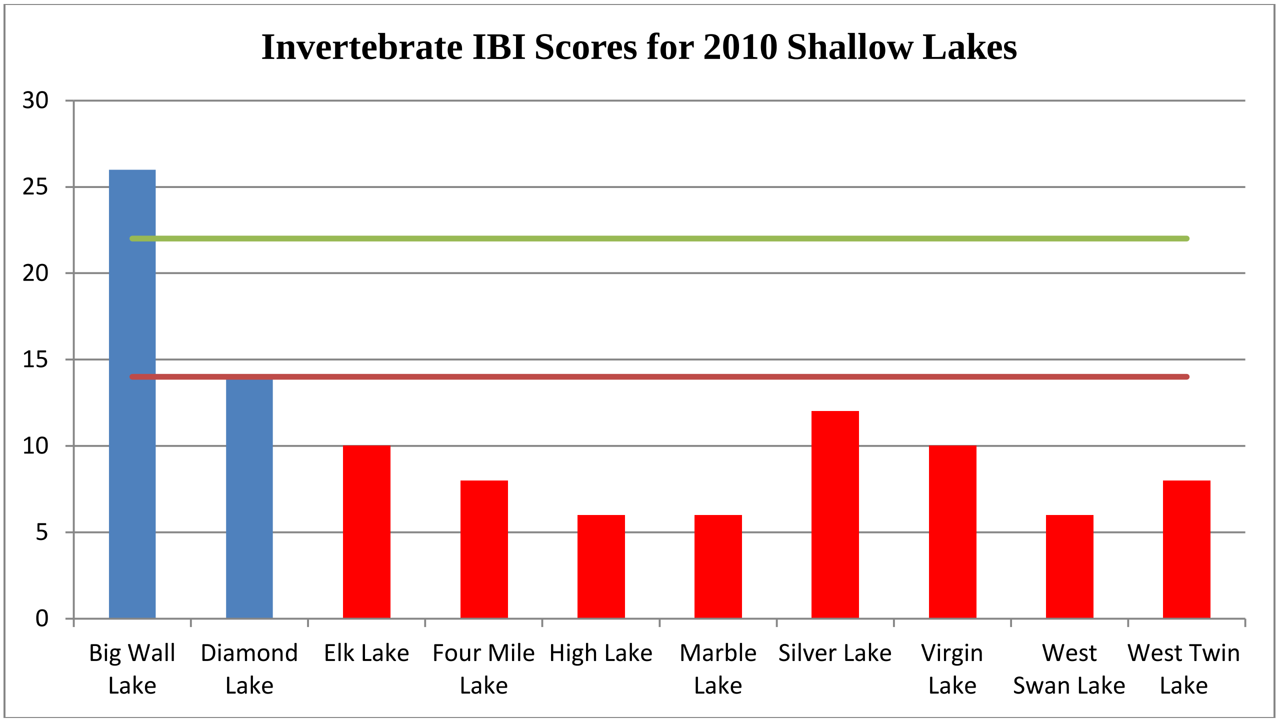


Figure 19. Invertebrate average abundance for restored and non-restored sites from 2010 to 2012.

Using Minnesota's Wetland Health Evaluation program Index of Biotic Integrity (IBI) for invertebrates categorized 2009 Big Wall Lake as being in excellent health (above the green line in Figure 20), 2012 Rice Lake and Diamond Lake as moderately healthy, and all other sites below the orange line in Figure 20 "poor health".



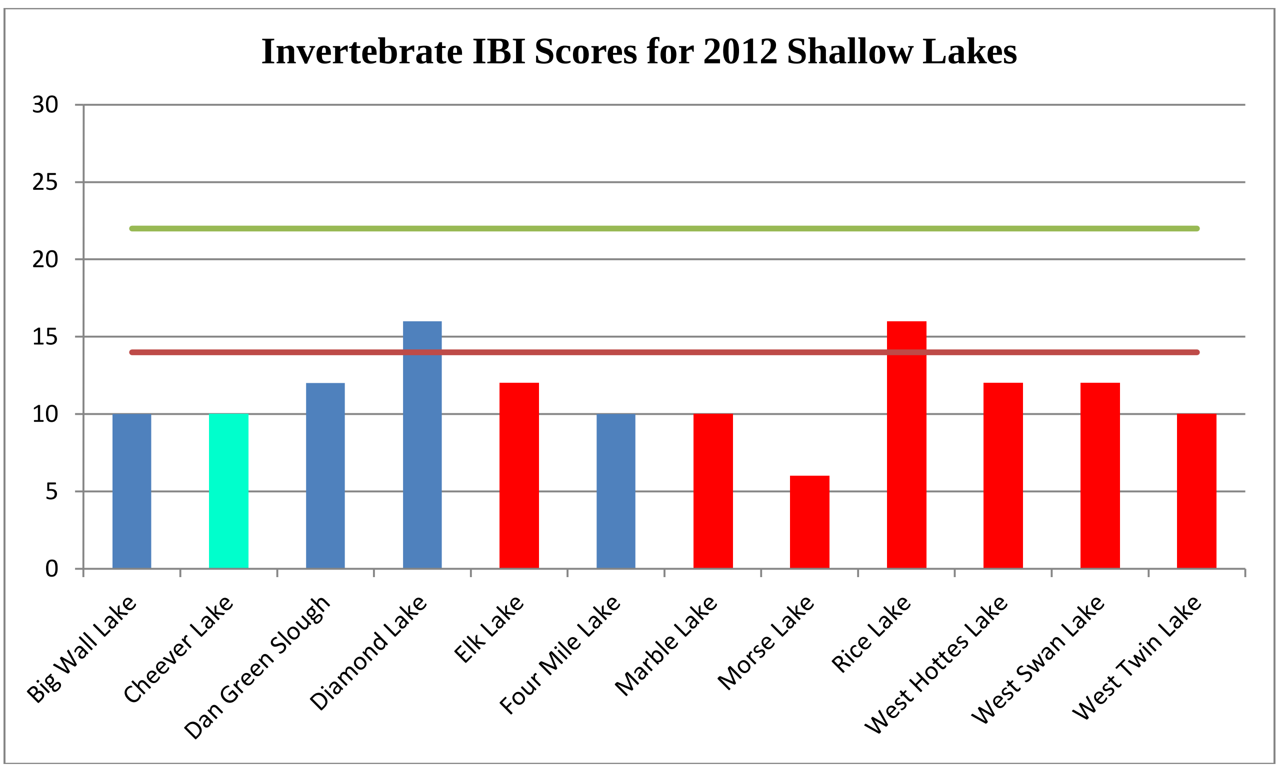


Figure 20. Invertebrate IBI scores for 2010 and 2012 sites using MN Wetland Health Evaluation. Note: The green line indicates the threshold for Minnesota's Wetland Health Evaluation Program's "Excellent" Wetland Health Assessment category (23-30), orange line indicates "Moderate" (15-22) & Poor" (6-14) is below orange line.

Aquatic Macrophyte Survey

Thirteen sites were sampled for aquatic macrophytes in 2010, three in 2011, and three in 2012 for a total of nineteen lake visits for vegetation surveys. Combined average macrophyte abundance for restored and non-restored sites from 2010 to 2012 were: 20% sago pondweed (*Potamogeton pectinatus*), 17% coontail (*Ceratophyllum demersum*), 17% narrow-leaf cattail (*Typha angustifolia*), 16% greater duckweed (*Spirodela polyrhiza*), 11% lesser duckweed (*Lemna minor*), 11% bladderwort (*Utricularia vulgaris*), 3% narrow-leaf pondweed (*Potamogeton strictifolius*), 3% filamentous algae, 2% softstem bullrush (*Schoenoplectus tabernaemontani*), and sixteen species with an average abundance of less than 2% per species.

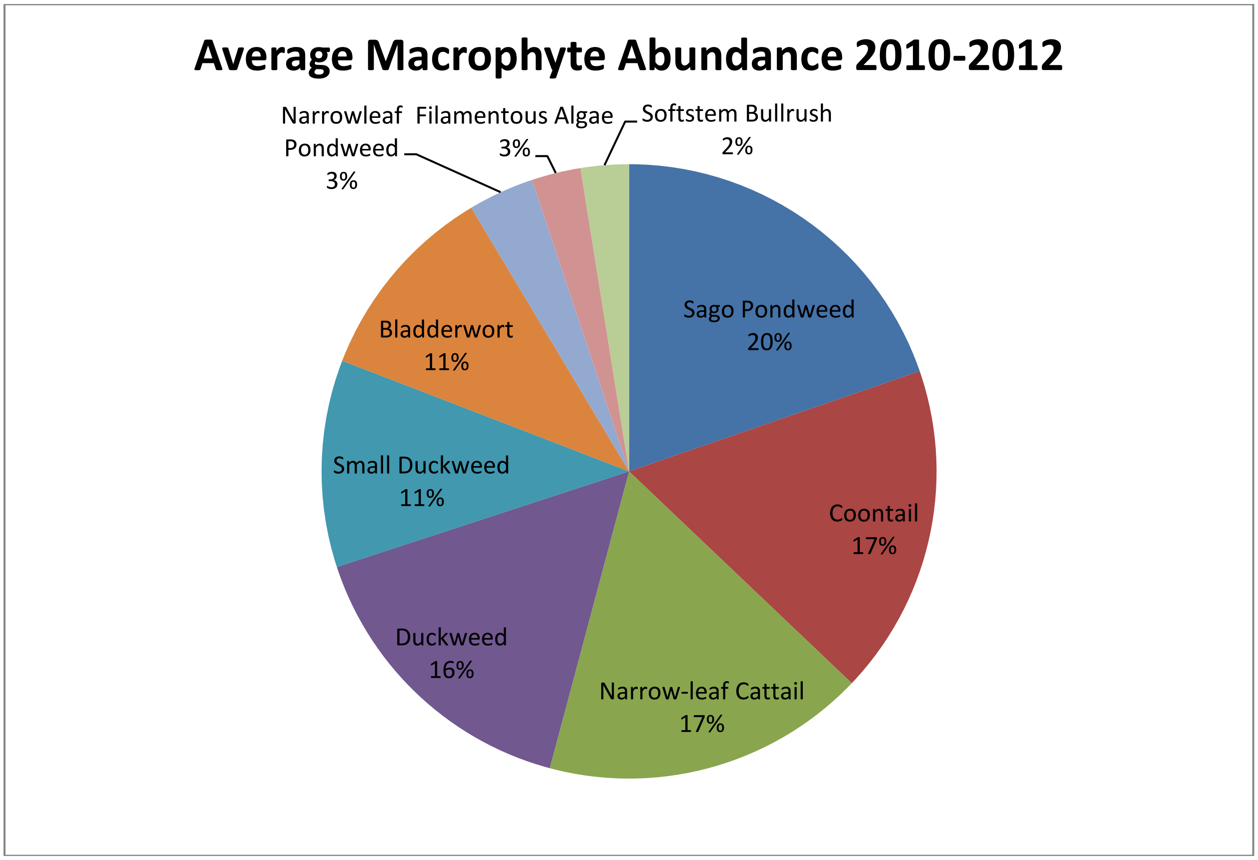


Figure 21. Average aquatic macrophyte abundance for all sites from 2010 to 2012.

Macrophyte abundance at non-restored sites and restored sites varied considerably (Table 3). Restored sites were comprised of four lakes, while non-restored sites were comprised of eighteen lakes. Narrow-leaf cattail had the highest abundance (45.59%) at restored sites while it only comprised 0.58% at non-restored sites and was the tenth most abundant species. Coontail, greater duckweed, sago pondweed, bladderwort, and lesser duckweed comprised over 25% of the abundance at restored sites. The top five species in non-restored sites by highest abundance were: sago pondweed, narrow-leaf pondweed, naiad (*Najas sp.*), muskgrass (*Chara sp.*), and coontail. Filamentous algae had a higher abundance at restored sites (6.67%) than non-restored sites (0.07%).

Species richness ranged from fifteen species at Four Mile Lake, to three lakes with no plants sampled (Morse Lake, West Twin Lake, and Twelve Mile Lake). Restored sites species richness ranged from ten species at Dan Green Slough, to fifteen species at Four Mile Lake. Non-restored sites species richness ranged from three lakes with no plants to thirteen species at West Hottes Lake, followed by Marble Lake with ten species and Silver Lake with nine species (Figure 22).

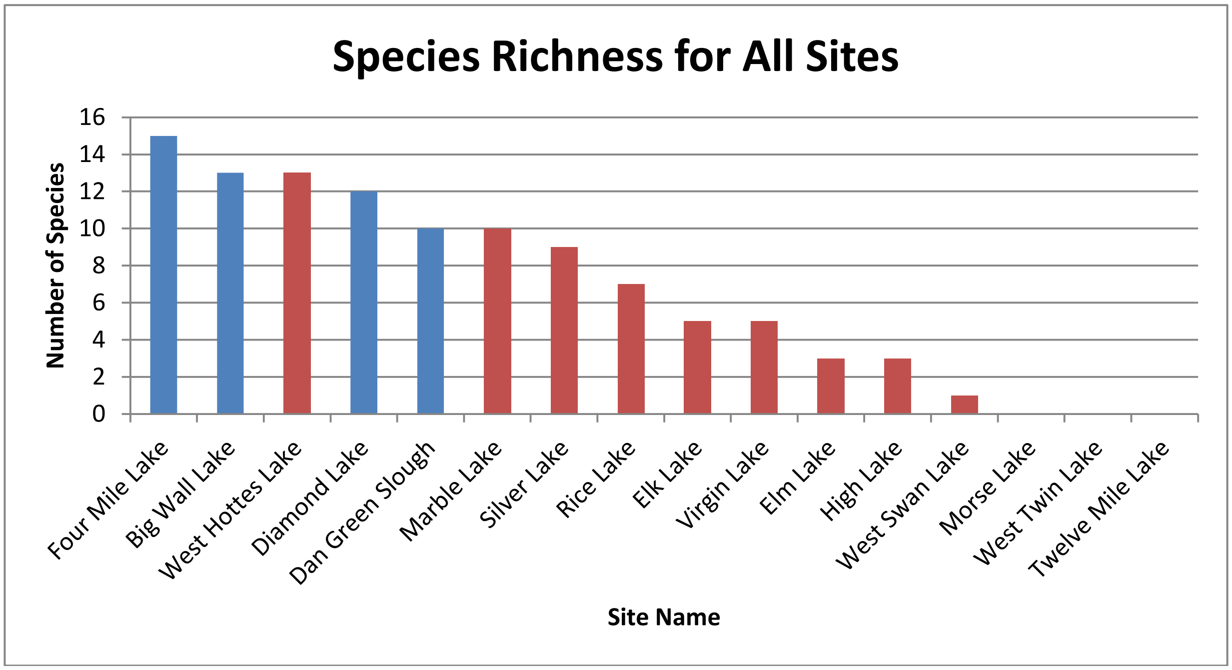


Figure 22. Aquatic macrophyte species richness for all sites from 2010 to 2012.

Restored sites contained 25 different species whereas non-restored sites had only 24 species. Restored sites were made up of eleven macrophyte species with an abundance of <1%, whereas non-restored sites with an abundance of <1% made up seventeen macrophyte species.

Table 3. Top Ten Macrophyte Species by Abundance and Site for 2010 to 2012.

Vegetation Species	Restored Sites
Narrowleaf Cattail	45.59%
Coontail	44.68%
Greater Duckweed	43.99%
Sago Pondweed	38.80%
Bladderwort	28.24%
Lesser Duckweed	28.10%
Softstem Bullrush	6.72%
Filamentous Algae	6.67%
Arrowhead	5.88%
Burr Reed	5.65%

Vegetation Species	Non-Restored Sites
Sago Pondweed	5.91%
Narrowleaf Pondweed	3.28%
Naiad sp.	1.89%
Muskgrass	1.80%
Coontail	1.70%
Curly Leaf Pondweed	1.68%
Northern Water Milfoil	0.79%
Lesser Duckweed	0.62%
Flat Stem Pondweed	0.59%
Narrowleaf Cattail	0.58%

The following species were found at restored sites and were not present at non-restored sites (from highest abundance to least): softstem bulrush, burr reed (*Sparganium americanum*), and reed canary grass (*Phalaris arundinacea*). The following species were found at non-restored sites and were not present at restored sites (from highest abundance to least): curly-leaf pondweed (*Potamogeton crispus*), waterweed (*Elodea canadensis*), floating pondweed (*Potamogeton natans*), wild celery (*Vallisneria americana*), and clasping-leaf pondweed (*Potamogeton perfoliatus*).

Zooplankton Survey

Average total zooplankton biomass was considerably higher for non-restored sites than for restored sites (Figure 23). Twelve Mile Lake had the highest zooplankton biomass of 5,602 ug/L while the highest biomass for a restored site was 828 ug/L (Big Wall Lake). Zooplankton biomass for non-restored sites ranged from 735 ug/L (Silver Lake) to 5,602 ug/L, whereas restored sites ranged in biomass from 178 ug/L (Four Mile Lake) to 828 ug/L. Average total biomass at restored sites was 398 ug/L while at non-restored sites, it was 2,271 ug/L.

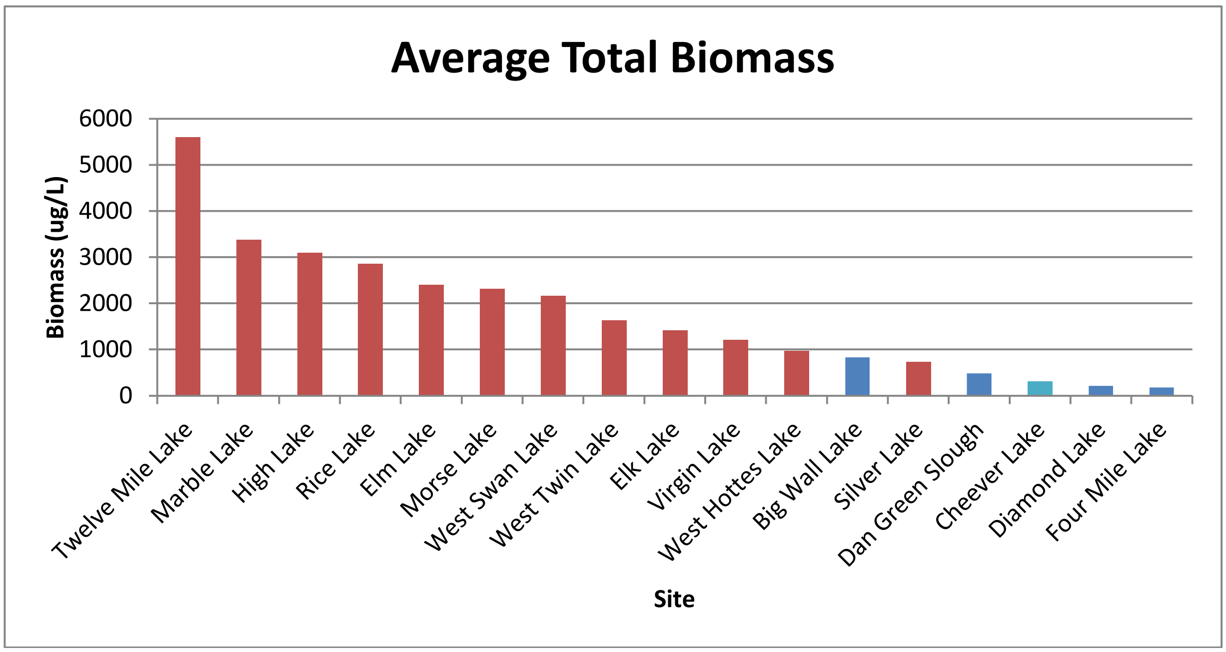


Figure 23. Average total zooplankton biomass for all sites from 2010 to 2012.

Species richness at restored sites ranged from 33 zooplankton species at Diamond Lake to 42 species at Four Mile Lake (Figure 24). Non-restored sites ranged from 19 species at Silver Lake to 34 species at West Hottes Lake. Average zooplankton species richness for restored sites was 37.5 species, while non-restored sites was 24.3 species. Total species richness for restored sites was 52 species, whereas non-restored sites had 35 total zooplankton species.

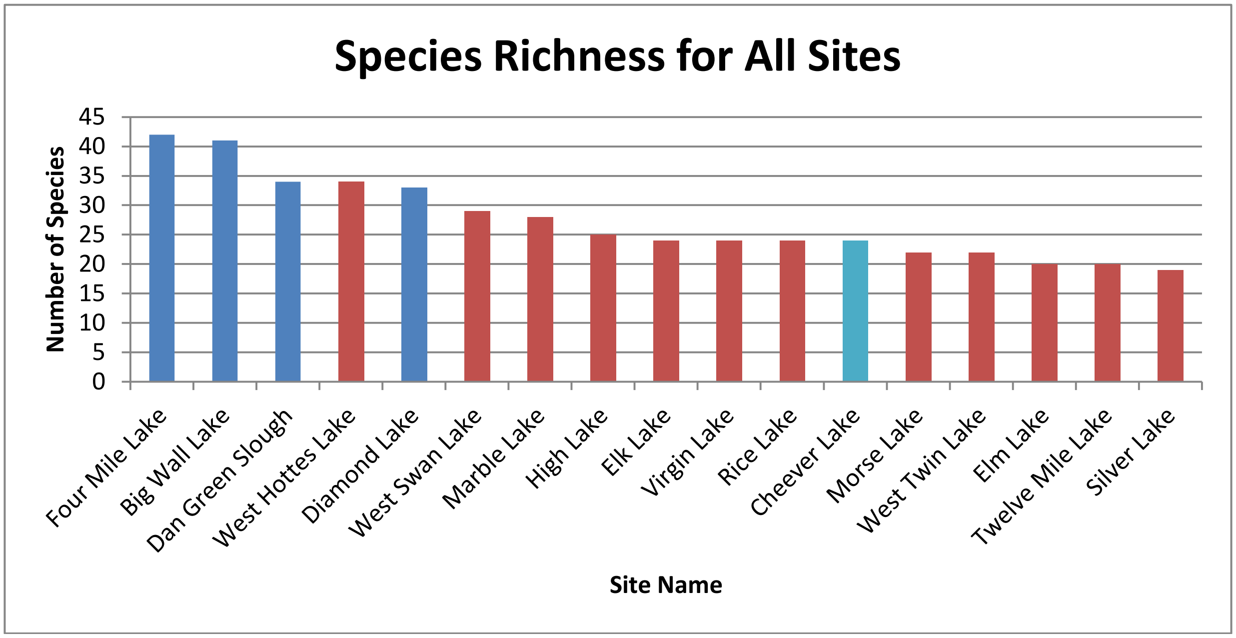


Figure 24. Zooplankton species richness for all sites from 2010 to 2012.

Average total rotifer biomass for all sites ranged from 1,071 ug/L at High Lake, a non-restored site, to 0.6 ug/L at Cheever Lake (Figure 25). Restored sites average rotifer biomass ranged from 11 ug/L at Diamond Lake to 63 ug/L at Big Wall Lake. Average rotifer biomass ranged from 45 ug/L at Twelve Mile Lake to 1,071 ug/L at High Lake for non-restored sites.

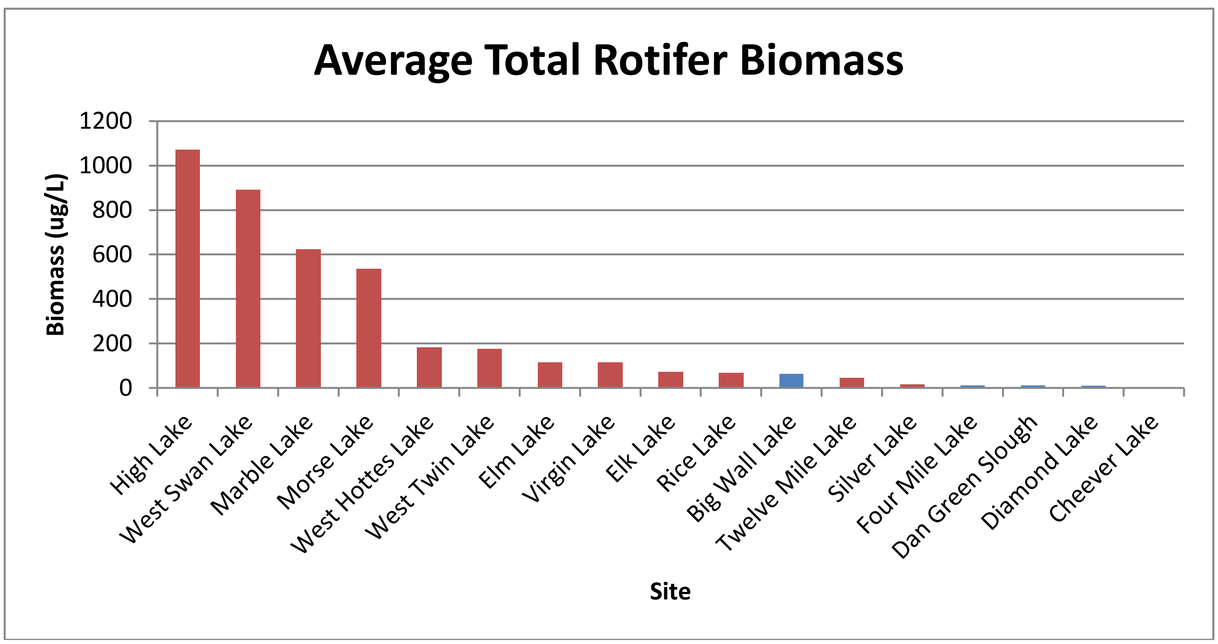


Figure 25. Average total rotifer biomass for all sites from 2010 to 2012.

Average percent rotifers for restored sites was 8.51% while non-restored sites were 14.85%. Percent rotifers at restored sites ranged from 1.4% in 2012 to 18.9% in 2011. Non-restored sites percent rotifers ranged from 9.64% in 2011 to 18.9% in 2010. Percent rotifer biomass from 2010 to 2012 for restored sites ranged from 2.8% (Dan Green Slough) to 14.3% at Big Wall Lake, whereas non-restored sites ranged from 1.3% (Twelve Mile Lake) to 32.7% at High Lake.

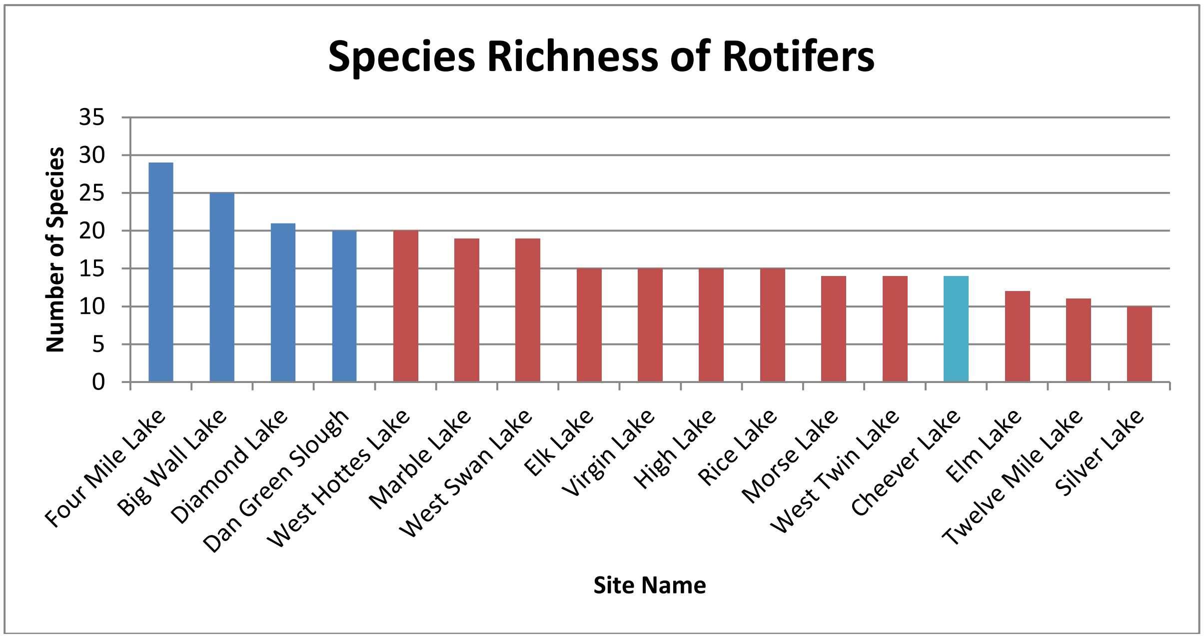


Figure 26. Rotifer species richness for all sites from 2010 to 2012.

Rotifer species richness at restored sites averaged 37.5 species per site, whereas non-restored sites averaged 24.3 species per site (Figure 26). Species richness ranged from 29 species at Four Mile Lake to 10 species at Silver Lake. Restored sites species richness ranged from 20 species at Dan Green Slough to 29 species at Four Mile Lake. Non-restored sites species richness ranged from 10 species at Silver Lake to 20 species at West Hottes Lake.

Phytoplankton Survey

Average phytoplankton composition ranged from 23% cyanobacteria for restored sites to 73% cyanobacteria for non-restored sites. Chlorophyta composition averaged 23% for restored sites and 7% at non-restored sites (Figure 27). Diatoms averaged 10% at restored sites versus 12% for non-restored sites. Dinophyceae composition averaged $\leq$ 0.2% for both restored and non-restored sites. Protozoa composition at restored sites averaged 9%, while non-restored sites averaged 2%. Chrysosphyceae composition at restored sites averaged 5% at restored sites and <1% at non-restored sites. Euglenophyta averaged 3% at restored sites and <1% at non-restored sites. Cryptophyta averaged 26% at restored sites while restored sites averaged 5%.

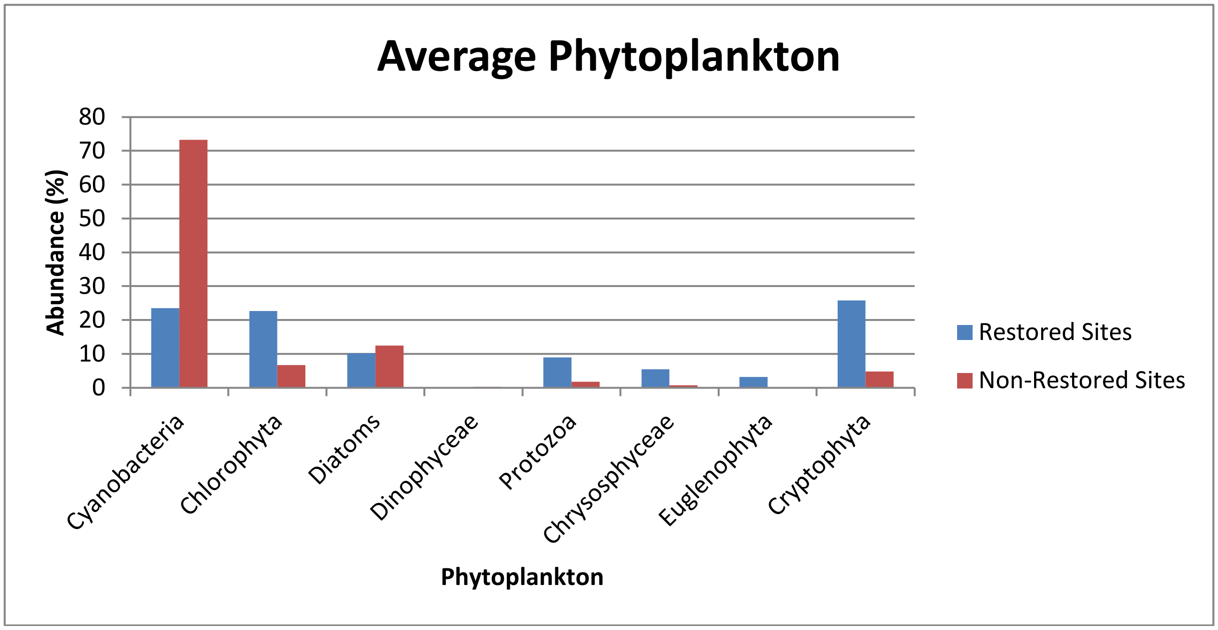


Figure 27. Average percent phytoplankton abundance for all sites from 2010 to 2012.

Cyanobacteria composition values by lake for all non-restored sites ranged from 42% at West Hottes Lake to 95% at Silver Lake from 2010 to 2012 (Figure 28). Restored lakes cyanobacteria composition ranged from 15% at Dan Green Slough to 39% at Diamond Lake. Cheever Lake had the lowest amount of cyanobacteria for all lakes at 12%.

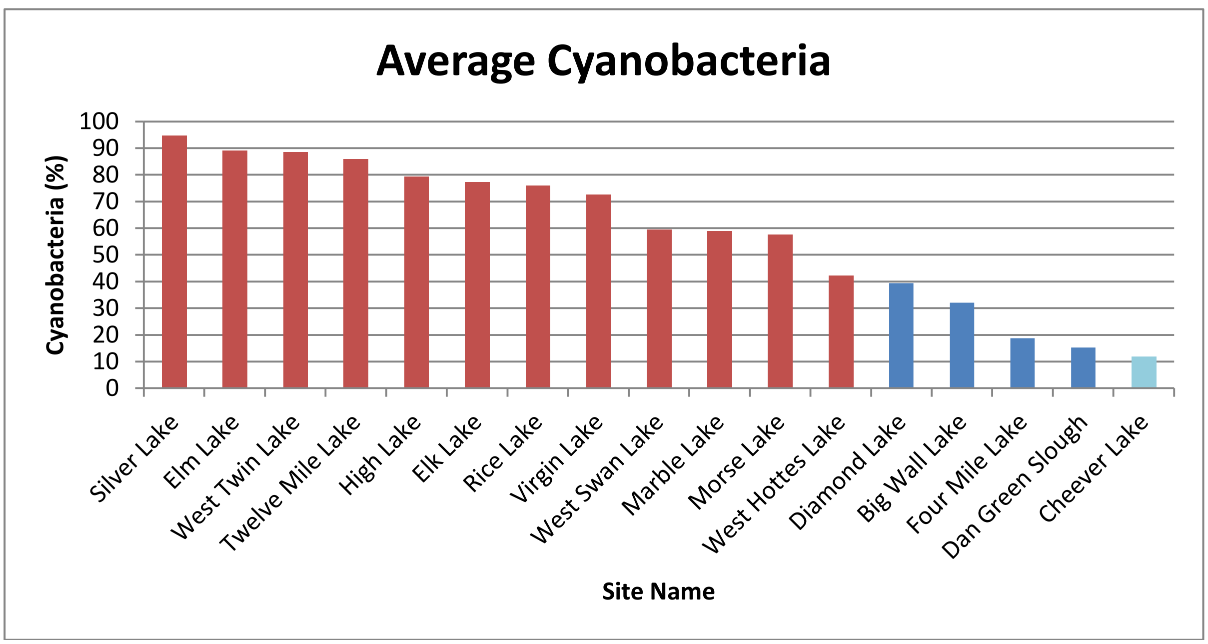


Figure 28. Average percent cyanobacteria for all sites from 2010 to 2012.

Average composition of Chlorophyta ranged from 31% at Big Wall Lake to <1% at Silver Lake. Cheever Lake Chlorophyta was 21%, while restored sites ranged from Dan Green Slough (6%) to Diamond Lake (14%), Four Mile Lake (21%), and Big Wall Lake (31%). Non-restored sites ranged from <1% (Silver Lake) to 12% at Morse Lake (Figure 29).

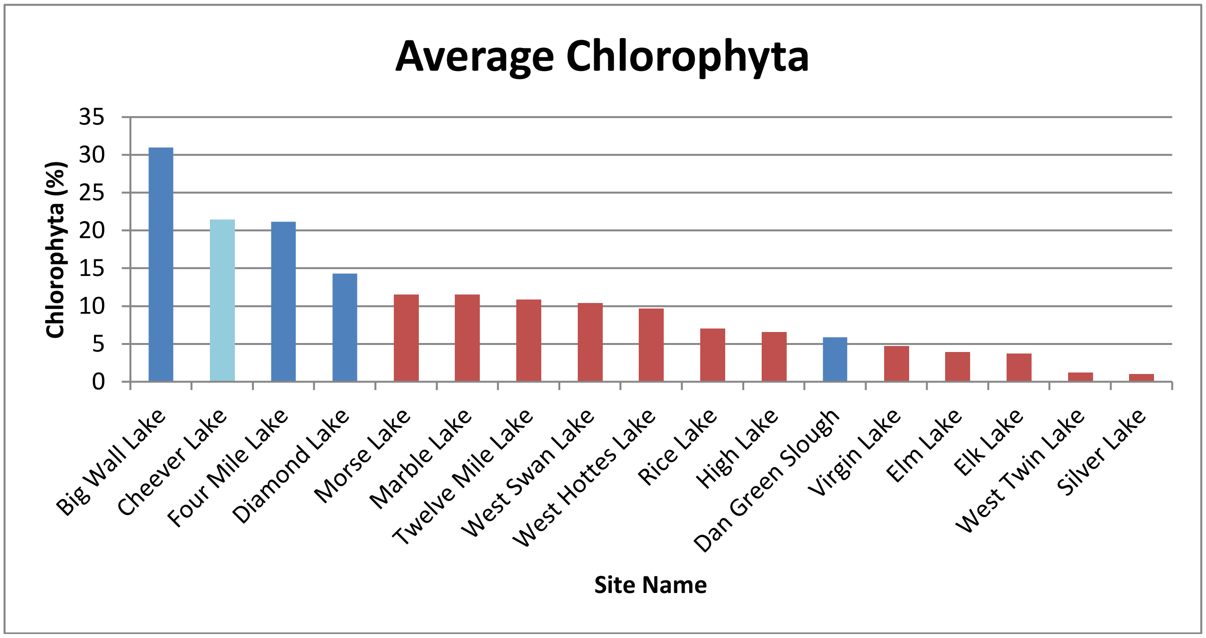


Figure 29. Average percent chlorophyta for all sites from 2010 to 2012. Restored sites are blue and red sites are non-restored. Reference site is teal.

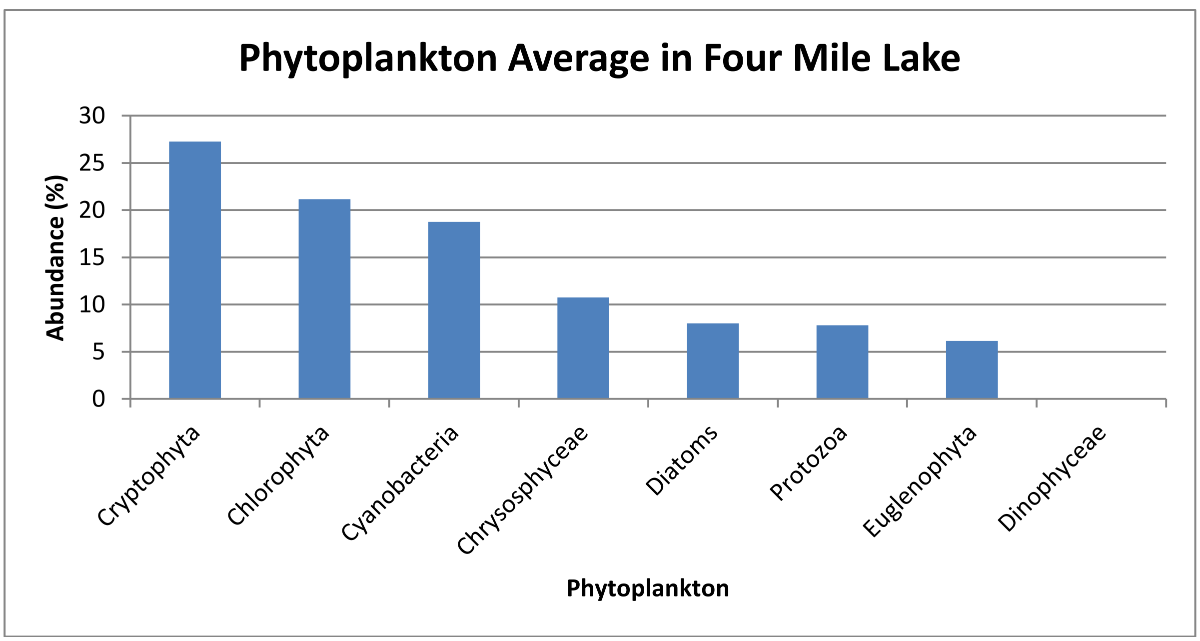


Figure 30. Phytoplankton percent abundance in Four Mile Lake from 2010 to 2012.

Four Mile Lake represents one of the healthiest sites in terms of phytoplankton composition (Figure 30). Four Mile Lake is composed of: Cryptophyta (27%), Chlorophyta (21%), Cyanobacteria (18%), Chrysosphyceae (11%), Diatoms (8%), Protozoa (8%), Euglenophyta (6%), and Dinophyceae (<1%).

Comparitively, the phytoplankton composition at one of the least healthiest sites, Silver Lake, consisted of: Cyanobacteria (95%), Diatoms (3 %), and Chlorophyta, Protozoa, Dinophyceae, and Cryptophyta all comprising <1% each. Chrysosphyceae and Euglenophyta were absent from Silver Lake (Figure 31).

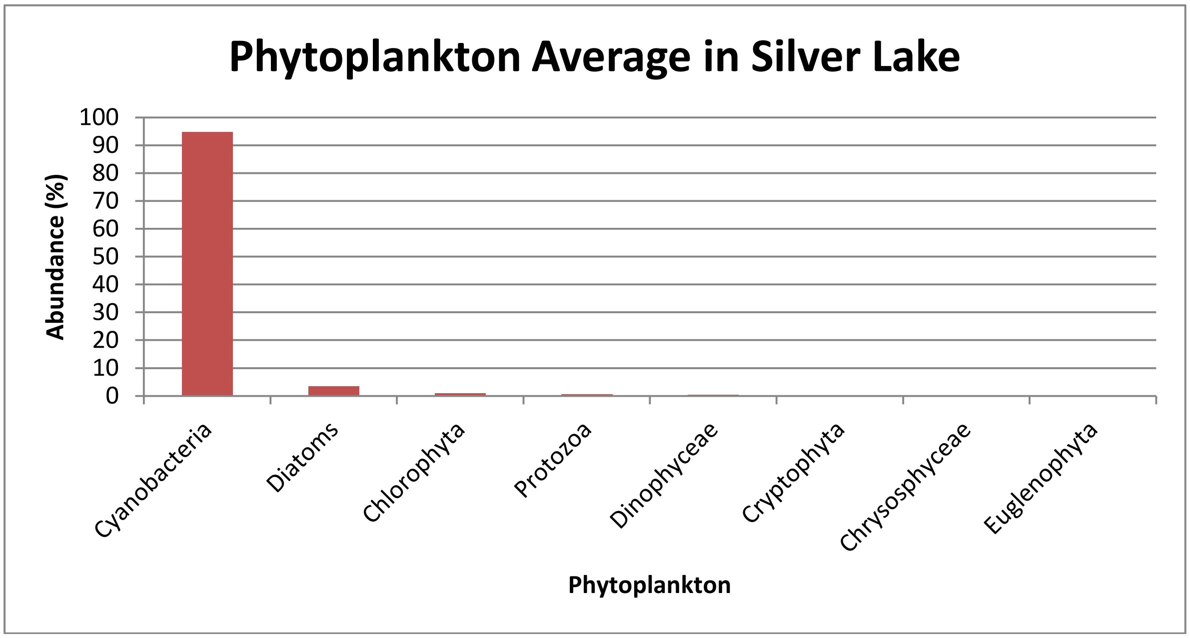


Figure 31. Phytoplankton percent abundance in Silver Lake from 2010 and 2011.

DISCUSSION

Shallow lake management has always been a challenge in Iowa and around the world. Shallow lakes are scattered throughout Northwest Iowa and in most of these lakes water quality lakes is less than desired. In fact, most of these lakes are turbid, algae-dominated systems with little to no vegetation, and poor sport fisheries comprised mostly of common carp and black bullheads. Successful restorations of deeper lakes have historically focused on reducing nutrient inputs by repairing the watershed and/or removing phosphorus-laden sediments from the lake. Successful shallow lake management strategies require intensive in-lake management strategies that can immediately flip the basin from a turbid-water state to a clean-water state, as well as long-term watershed protection efforts that help maintain clean water over time.

Shallow lakes differ substantially from deeper lakes in many respects. Shallow lakes usually exist in either of two alternative stable trophic states with or without any change in the nutrient budget of the lake. These lakes can exist as very turbid, algae-dominated systems with little to no vegetation, or as clear water, macrophyte dominated systems. In shallow lakes, the benthivorous and planktivorous fishes along with wind and wave action and in some cases heavy boating traffic can perpetuate the algae dominated system.

By controlling or removing the factors perpetuating the algae dominated turbid system, it is possible to "flip" the system into a clear water macrophyte dominated system (Scheffer, 1993). The positive impacts of emergent and submergent vegetation on water quality are due to several factors. Rooted vegetation prevents resuspension of sediments into the water column by anchoring bottom sediments and suppressing wind and wave action. Rooted plants provide habitat for periphyton, zooplankton, and fish species commonly found in clear water lakes. Rooted vegetation also ties up nutrients, making them unavailable for algae. Some plants also release allelopathic substances into the water suppressing algae growth. Many of these mechanisms are difficult to assess and vary among water bodies; however, their combined effect stabilizes the clear water trophic state (Scheffer et al., 1993). Both the clear water macrophyte state and the algae dominated state are stable, and it takes a major perturbation to move from one state to another (Scheffer et al., 1993). Three methods that show great promise to cause the shift from the turbid to the clear water state are benthivorous fish control, heavy piscivore stockings (to control both benthivorous and planktivorous fishes), and water level draw downs (Scheffer et al., 1993). The goal of this project has been to develop methods that managers can use to shift and maintain shallow lakes in a clear water state.

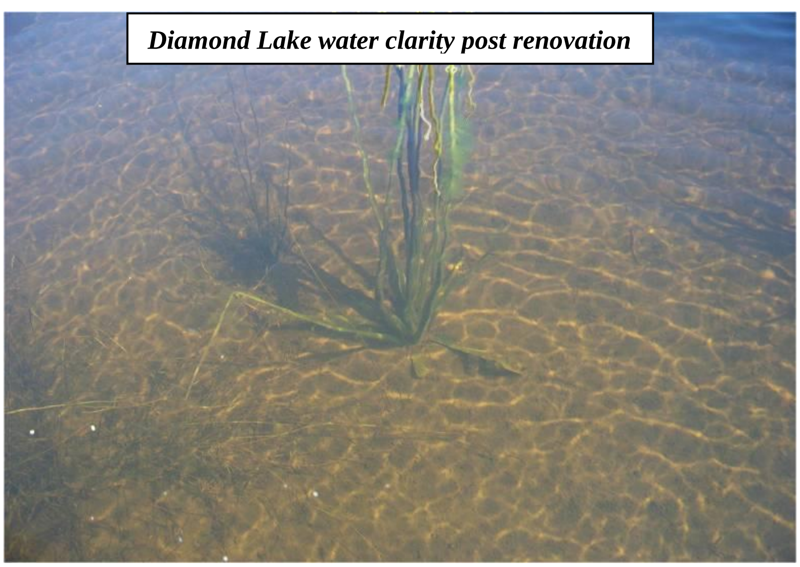
Many natural Lakes in Northwest Iowa are characterized as shallow, windswept systems that exhibit poor water quality. Significant watershed changes and the introduction of common carp in the late 1800's have forever made management of these water bodies a challenge. Through work accomplished on the projects listed below, great strides have been made in our understanding of these systems. These ground breaking projects in Iowa will undoubtedly lead to others as the health to these unique water bodies is restored. Success is also being measured in public education and outreach. Communities and user groups are coming together to make these projects truly successful demonstration models, not only for improving water quality, but for fostering partnerships in the long-term active management required to maintain the health of these lakes.

Iowa DNR's Watershed Monitoring and Assessment Section and Wildlife and Fisheries Bureaus, in cooperation with Ducks Unlimited, have established a list of shallow lakes prioritized for restoration. The focus of the Iowa DNR Lake Restoration Program is on shallow lakes that support both fishing and wildlife benefits. The following four lakes have been restored back to a clear water state either prior to, or during the course of this three year study.

Diamond Lake, Dickinson County

Aerial photo with Diamond Lake at approximately half pool.

During winter 2006-07, the initial efforts to enhance this 166-acre basin were completed with the installation of a drawdown tile designed to allow the lake to be periodically dewatered to eliminate rough fish and to allow for the germination of aquatic plants and consolidation of bottom sediments. Excessive rain in late summer 2007 prevented a successful drawdown. A winter rotenone project in January 2008 eliminated the few remaining rough fish in the lake. A successful drawdown was realized in summer 2008 through the continuous use of the drawdown tile and the temporary use of an auxiliary diesel pump, which was purchased with Iowa DNR Lake Restoration funds (Figure 32). The outlet of the lake was also lowered about 0.5' to a more natural elevation, which will prevent excessive shoreline erosion, tree toppling, and should sustain water levels which are more conducive to aquatic plant growth. Despite a cool spring, regrowth of vegetation did well over the summer.



Diamond Lake water clarity post renovation

A "reef" fish barrier was installed during winter 2008-2009 to prevent the reinfestation of rough fish into Diamond Lake. The barrier is best described as a flow-through rock weir. Currently, the lake contains exceptionally clear water and has diversified stands of emergent vegetation on the lake's perimeter and submergent vegetation within the lake. Migratory bird use has been excellent with several thousand shore birds and waterfowl observed on the lake during early fall 2009. Fingerling yellow perch were stocked spring 2009 and northern pike were stocked in 2010. The basin was brought to full pool during spring 2010.

The National Fish Habitat Action Plan unveiled Diamond Lake as one of its 2010 10 "Waters to Watch" list, a collection of rivers, streams, lakes and watershed systems that will benefit from strategic conservation efforts to protect, restore or enhance their current condition. These waters represent a snapshot of current conservation efforts that the Action Plan is undertaking to provide cleaner and healthier habitats for the many fish and wildlife species and people who call these areas home.

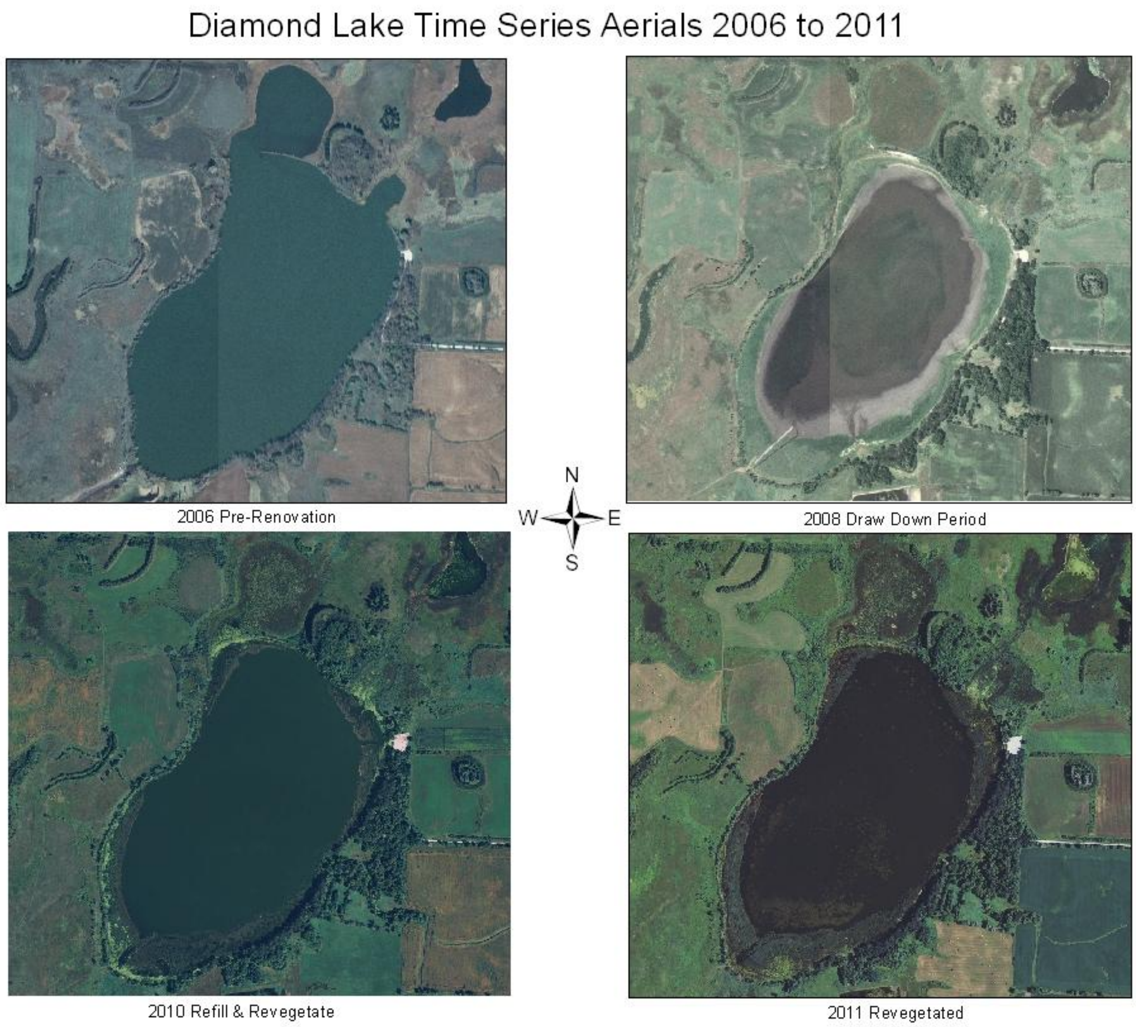


Figure 32. Diamond Lake time series aerial photographs from 2006 to 2011 showing pre-renovation to revegetated condition.

The Diamond Lake project focused on improving water quality by shifting the lake to a clear water state using water-level management to consolidate bottom sediments, re-establish aquatic plants, and control common carp populations. The restoration of Diamond Lake is Iowa's inaugural shallow lake restoration project providing resource management professionals with experience and expertise for managing shallow lakes. The project also provides stakeholders a demonstration of the restoration potential for other shallow lakes. To date, water quality, plant abundance, and diversity are still good. Yellow perch and northern pike growth is excellent. This is also the first time in recent history that diving ducks were found using the lake in spring and fall, which is indicative of an ample food source for these species.

Dan Green Slough, Clay County

The donation of a key tract of land in 2008 facilitated the installation of a pump system and fish barrier on the 311-acre Dan Green Slough during fall 2008 and winter 2008-09. A subsequent temporary draw down of the basin during spring and summer 2009 resulted in the eradication of rough fish, the consolidation of bottom sediments, and the re-establishment of over 250 acres of soft stem bulrush and other beneficial emergent aquatic plants. The basin was kept partially dry during the 2010 growing season to allow for the continued growth of emergent vegetation and the establishment of submergent plants. The basin was brought to full pool during spring 2011.

A local bird surveyor recently informed the DNR that he personally observed every shore/wading bird that was expected to be in this region of Iowa plus a few rare ones that were not expected. The mudflats had a tremendous response to emergents (i.e. softstem bulrush) and once water was returned, submergents (i.e. sago pondweed) flourished. Dense vegetation provided excellent fall habitat for migrating ducks. There was heavy duck hunter use throughout the season and many had good to excellent luck.

Draining of Pickerel Lake (Buena Vista Co.) and removal of old outlet structure.

New outlet/water control structure at Pickerel Lake.

Four Mile Lake, Emmett County

A partial drawdown initiated during summer 2008 allowed for the successful construction of a fish barrier and the addition of in-lake drawdown channels in Four Mile Lake during the fall of that year. Continuation of the drawdown in summer of 2009 allowed for the eradication of rough fish, the consolidation of bottom sediments, and the establishment of beneficial submergent and emergent vegetation in the 200-acre basin. Presently, the basin is at full pool, contains very clear water, supports robust populations of submerged plants and associated invertebrate populations, and provides excellent migratory bird habitat. The restored Four Mile Lake fulfills its intended function of being a stepping stone lake by providing exceptional migratory habitat for diving ducks and other migratory water birds that rely on healthy aquatic environments to complete their life cycles.

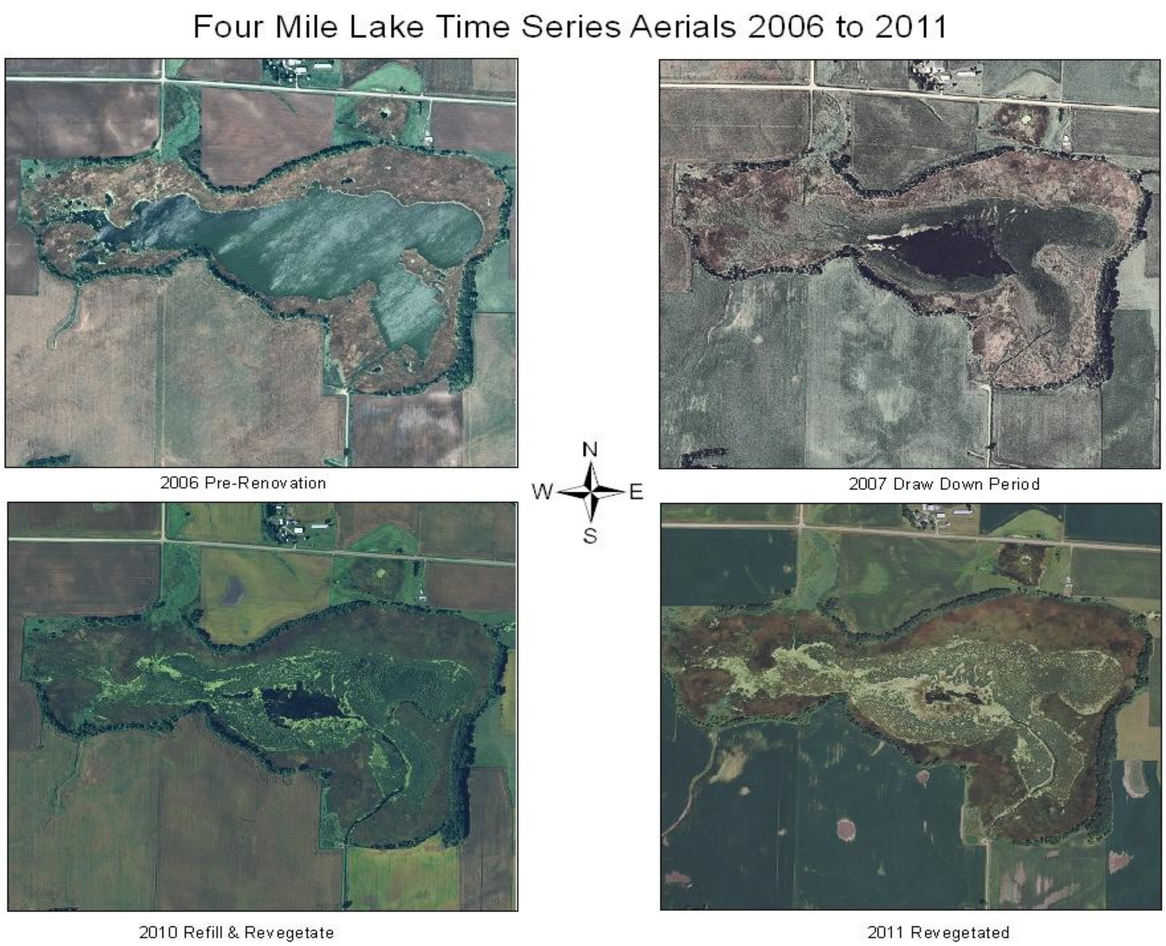


Figure 33. Four Mile Lake time series aerial photographs from 2006 to 2011 showing pre-renovation to revegetated condition.

Big Wall Lake, Wright County

Common carp stirred up sediment on the shallow, 978-acre Big Wall Lake, making water too muddy for normal plant and animal growth. Big Wall Lake was listed on the 303d impaired list for invasive species. As part of the project starting in 2006, the existing outlet was removed, the lake was completely drawn down, and carp were eliminated. This restored a high quality hemi-marsh habitat with diverse wetland plants and animals, excellent for ducks and other waterfowl; 10,000 waterfowl once again use the lake during migration.

The lake (Virgin Lake) was drained to reestablish vegetation and remove undesirable fish.

Chemical Data

To address shallow lakes water quality, Iowa DNR uses either a summer growing season median value for chlorophyll of greater than 65 (>33 ug/l), or a growing season TSS median value of 30 or greater to identify a Section 303(d) impairment (Figure 34 & 35). The rationale behind this impairment threshold is to provide a base level of water clarity that allows growth of submersed aquatic vegetation in shallow lakes and wetlands. The chlorophyll threshold is based on Carlson's trophic state index; the TSS number is from work by John Sullivan (Wisconsin DNR) on the amount of light penetration needed to allow growth of submersed aquatic vegetation.

Since these values are not WQ standards or criteria, they are referred to as "impairment thresholds". They are, in essence, numeric translators for the following narrative water quality standard:

> *Such waters shall be free from substances, attributable to wastewater discharges or agricultural practices, in quantities which would produce undesirable or nuisance aquatic* life.

Concentrations of chlorophyll in non-restored sites, with the exception of West Hottes Lake, tend to be much greater than restored sites. Increased nutrient loads, either internal re-suspension or external sources, and increasing chlorophyll trends can indicate eutrophication in aquatic systems.

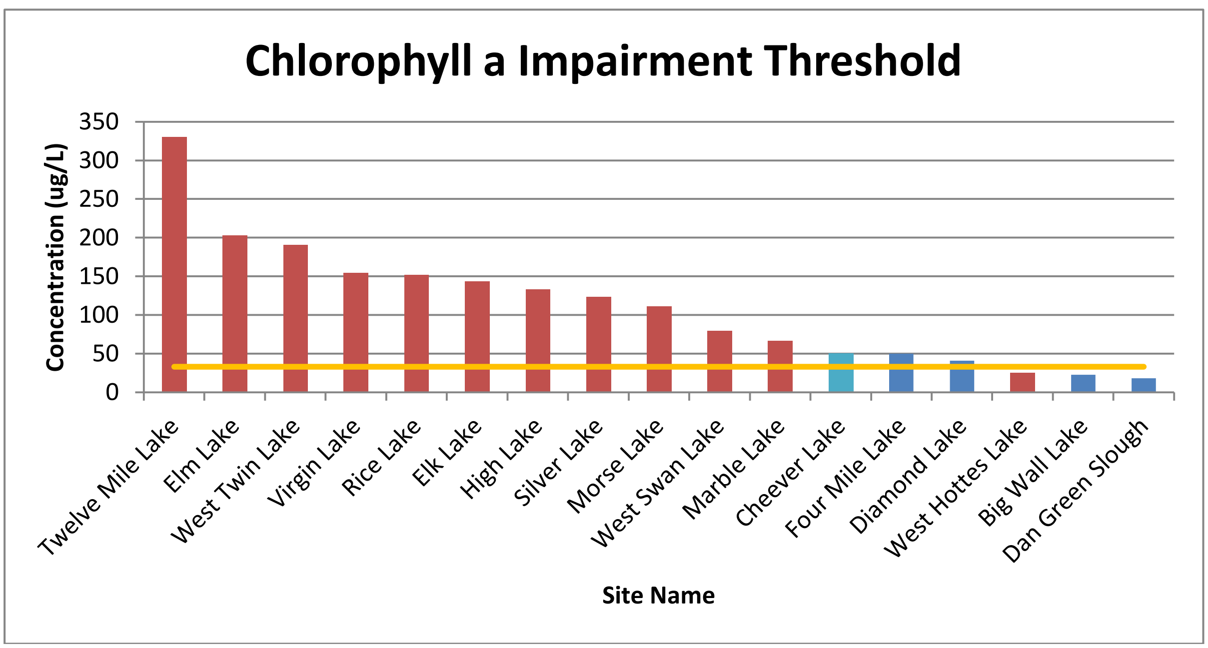


Figure 34. Chlorophyll impairment threshold level (<33 ug/L) for all lakes from 2010 to 2012.

High levels of total suspended solids impact the ability of a shallow lake to support the growth of submersed aquatic vegetation. The elimination of submersed aquatic vegetation can degrade habitat quality such that undesirable aquatic species such as cyanobacteria, common carp, and fathead minnows dominate the ecosystem.

Total suspended solid values at restored sites are significantly lower than at non-restored sites. Cheever Lake, based on sampling experience at this site and difficulty accessing the main body of the lake, may be slightly skewed in TSS readings due to re-suspension of bottom sediments and organic material during sample collection. Often times between 2010 and 2012 samples for Cheever Lake had to be collected very near the boat launch in much shallower water than would typically be sampled in the main body of the lake.

Non-restored sites, with the exception of West Hottes Lake, all exceeded the TSS impairment threshold by having values which are above the growing season median value of 30 ug/L. Elevated TSS in non-restored sites can be attributed to the nature of these shallow open water systems. Exposure to wind and wave action, as well as re-suspension of bottom materials and nutrients that drive cyanobacteria blooms are a key factors which affect TSS readings. Elevated TSS and TVSS values can also be caused by a large rough fish population, as these fish will stir up bottom sediments when foraging for food.

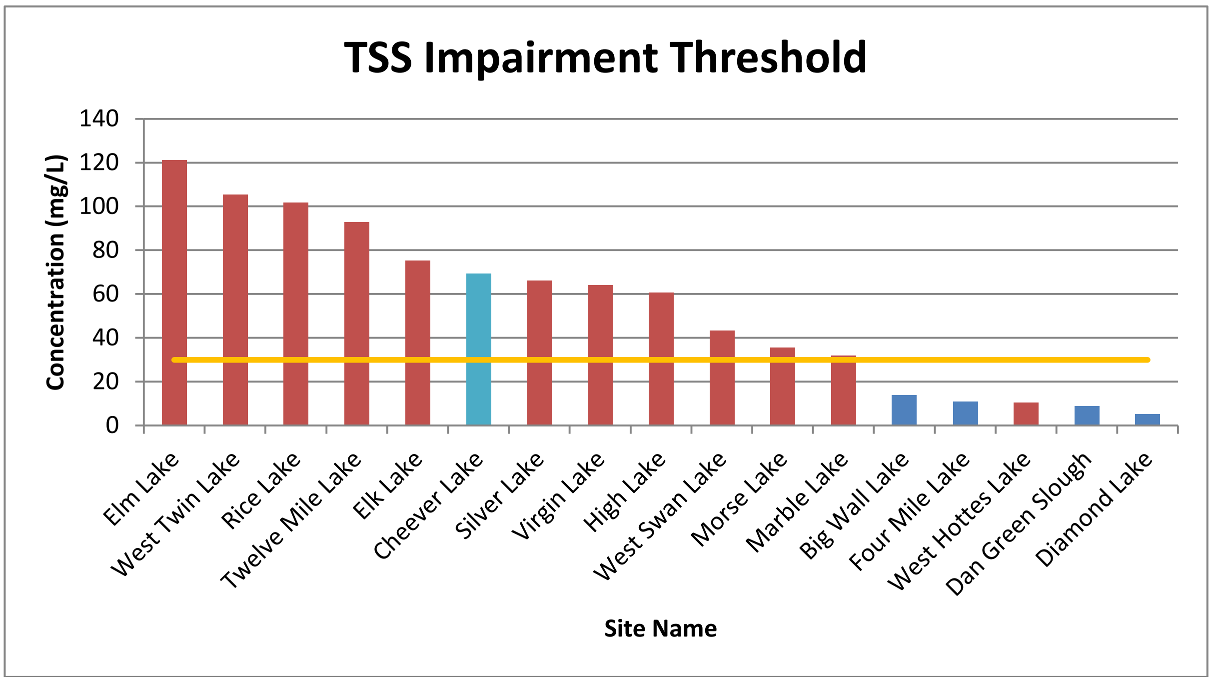


Figure 35. TSS impairment threshold level (30 ug/L median) for all lakes from 2010 to 2012.

Like most chemical constituents present in the environment, phosphorus is cyclic. Phosphorus is present in both the dissolved phase, commonly measured as orthophosphate, and the particulate bound phase, which is represented in the measure of total Phosphorus. Under natural conditions, phosphorus is slowly released from rock and sediment deposits. Human activities have accelerated this naturally slow phosphorus cycle through agricultural practices, industrialization, land development, and urbanization.

Total Phosphorus is an essential nutrient for plants and animals. It is naturally limited in most fresh water systems because it is not as abundant as carbon and nitrogen; introducing a small amount of additional phosphorus into a waterway can have adverse effects. Eutrophication is the result of excess nutrient availability and over enrichment, often identified by toxic algae blooms (e.g., cyanobacteria) or oxygen depletion. Algal blooms can result in fish kills, human illness, and even death of mammals and birds.

Total P levels are lower in restored sites because, as a part of the restoration process, the water was drawn down and the sediment was allowed to dry and consolidate. As the water returned, aquatic macrophytes were established, and their roots stabilized soil which phosphorus particles bound to. The continual disruption and re-suspension of bottom sediments at non-restored sites by rough fish and wind and wave action explain the constant elevated Total P levels at these sites monthly as well as annually. Non-restored sites, until restored through drawdown, rough fish removal, and macrophyte re-colonization, will continue to exhibit internal nutrient loading.

On average, restored sites displayed higher concentrations of orthophosphate than non-restored sites. It is important to note that non-restored sites will continue to exhibit internal nutrient loading unless they are restored using a similar process as described above. Elevated orthophosphate levels at restored sites were found exclusively at Big Wall Lake. Total P levels at Big Wall Lake were also higher than average for restored sites. The cause of the raised orthophosphate and total phosphorus concentrations at Big Wall Lake is unknown, however, the increased level of this nutrient does not appear to be greatly affecting the general health of the system, as the majority of the other chemical, physical, and biological parameters fall within normal ranges. Typically, elevated orthophosphate levels drive algal blooms, but since Big Wall Lake is a nitrogen limited system, the growth of algae is stunted.

Total Kjeldahl nitrogen or TKN is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+). TKN concentrations track the cyclic nature of Total N concentrations, both of which tend to facilitate the growth of phytoplankton. Non-restored lakes displayed higher TKN concentrations when compared to restored lakes, which is consistent with phytoplankton biomasses.

Physical Data

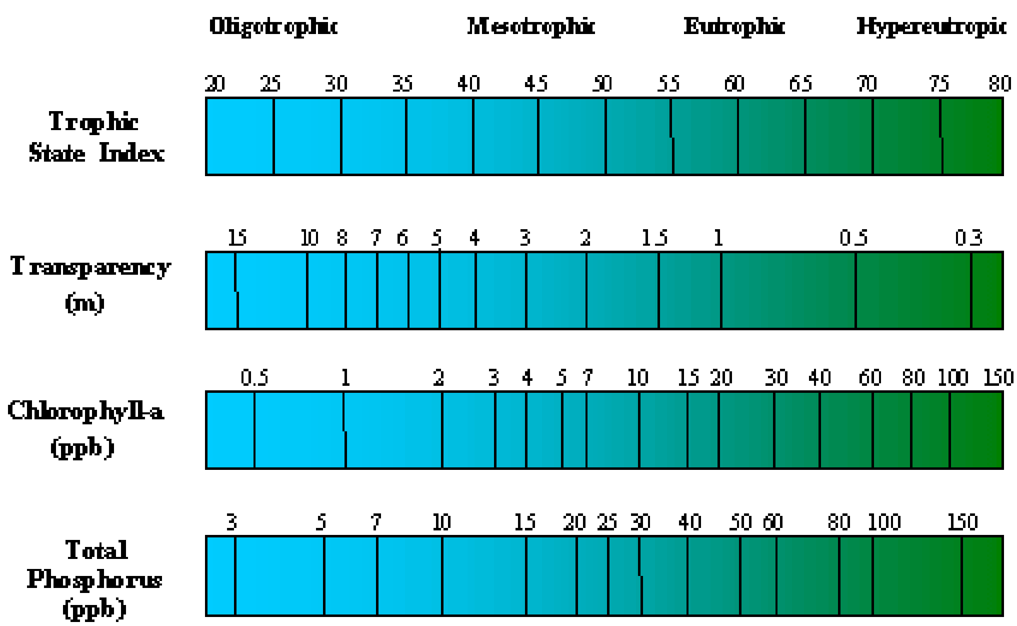
Lake Trophic Status

Total phosphorous (TP), chlorophyll-a (Chl-a), and Secchi transparency are closely interrelated and are collectively used to characterize the trophic status of lakes. Carlson's Trophic State Index (TSI) is used to evaluate the trophic status of a lake and to interpret the relationship between TP, Chl-a, and Secchi transparency (Carlson, 1977). This index was developed from the interrelationships of summer Secchi transparency and the concentrations of surface water Chl-a and TP.

TP and Chl-a are in micrograms per liter (ug/L) and Secchi transparency is in meters, while TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of 10 units represents a doubling of algal biomass. The following is a list of TSI ranges and the typical observations associated with them (Figure 36). This index is based on the interrelationship of the three variables and allows for the prediction of any variable.

Figure 36. Carlson's Trophic State Index.

TSI<30	**Classical Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.**
TSI 30-40	**Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.**
TSI 40-50	**Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.**
TSI 50-60	**Lower boundary of classic eutrophy: Decreased transparency, anoxic hypolimnion during the summer, macrophyte problems evident, warm-water fisheries only.**
TSI 60-70	**Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.**
TSI 70-80	**Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.**
TSI>80	**Algal scums, summer fish kills, few macrophytes, dominance of rough fish.**



__After__ Moore, l. and K. Thornton, [Ed.] 1988. Lake and Reservoir Restoration Guidance Manual. USEPA>EPA 440/5-88-002.

Secchi depth will not be used for shallow lakes monitored from 2010 to 2012 even though calculations were made and the Secchi TSI shows very similar results to that of Chlorophyll-a. The primary reason for this decision was the fact that numerous monthly Secchi depth values for restored lakes indicated the Secchi disc was visible all the way to the bottom of the lake. Without knowing the exact Secchi depth reading it was not deemed an acceptable parameter for which to calculate lake Secchi TSI for comparative purposes. Another parameter, TP, was calculated but due to the time of year the data was collected, Chlorophyll-a remains the most reliable method with which to calculate TSI. The TP method yielded TSI results similar to that of the Chlorophyll-a method.

Chorophyll A was determined to be the most accurate indicator of lake trophic status for shallow lakes sampled in the summer, and the other two methods will be considered as supplemental calculations only. Chlorophyll-a TSI values at restored sites ranged from 57 in 2011, 66 in 2012, to 68 in 2010. These values place restored lakes in the eutrophic category, common for most Iowa lakes. According to Carlson's TSI these lakes are the lower boundary of eutrophy having decreased transparency, anoxic hypolimnion during the summer, evident macrophyte problems, and a warm water fishery.

Comparitively, non-restored sites TSI values for Chlorophyll-a ranged from 76 in 2010 and 2011 to 79 in 2012. This category of lakes commonly exemplifies heavy algal blooms throughout the summer, dense macrophyte beds with extent limited by light penetration. This category of non-restored lakes would be categorized as hypereutrophic. Numerous non-restored lakes exhibited TSI scores >80 (Ex. Elk Lake, High Lake, Morse Lake, Virgin Lake). Elm Lake and West Twin Lake TSI values exceeded 80 in all three years, indicating systems which are dominated by rough fish, have a high probability of algal scum development, and which contain few aquatic macrophytes. These conditions could also cause summer fish kills.

When considering all the physical parameters collected, Secchi depth and turbidity show the greatest difference between restored and non-restored sites. In all three years the average Secchi depth values for restored sites were at least two times those of the non-restored sites, and in 2012, restored sites were three times the average depth of non-restored sites. As mentioned previously, had some of these shallow lake systems not been constrained by their depths, those differences in Secchi readings between restored and non-restored lakes would have been even greater. Abundance of submergent vegetation also effected Secchi depth readings over the course of monitoring, primarily at restored

Secchi disc reading at Elm Lake 2012

sites. Average Secchi readings at restored sites ranged from 66 cm to 81 cm with the greatest individual reading at Diamond Lake of 152 cm.

Turbidity averages from 2010 to 2012 were vastly different between restored and non-restored sites. The average turbidity value for non-restored sites in 2010 were 11.4 times greater than restored sites, 17.1 times greater in 2011, and 15.2 times greater in 2012. In 2012, Elm Lake averaged the highest turbidity reading of 218 NTU's, with a maximum reading of 460 NTU's. Twelve Mile Lake was similarly turbid with an average reading of 170 NTU's in 2012. These lakes, when visited for sample collection, had a very noticeable greenish color to them during the majority of site visits. The picture above depicts the severity of degradation seen in many of the non-restored lakes, and highlights the work needed to get these systems restored back to a clear water state.

Biological

Fish Survey
Removal of rough fish species was a part of the restoration process in which four of the lakes in this project underwent. While conducting fish surveys in 2011, black bullheads were captured at two of the restored sites, but in very low numbers. It is likely that this rough fish species, as well as other similar species, may be reintroduced by the general public over time, even though signage at these sites indicates the restoration efforts put forth, and the importance of keeping rough fish out. The reduced population of rough fish in these restored systems has undoubtedly had a positive impact on the overall water quality in these systems. Replacement of rough fish in these restored sites, like Diamond Lake, with game species such as yellow perch and northern pike has shown impressive growth rates in desirable fish species which has increased angling pressure, and recreational use by the general public.

Bullheads schooling 2012

Non-restored sites, such as Rice Lake, will also see exploitation of their fishery by the general public, despite the fact that the water quality is poor. It is interesting to note that a large, potentially state record, white bass was captured during the summer 2012 while fyke netting Rice Lake. The white bass was subsequently returned to the lake. Many of these non-restored lakes are teaming with rough fish populations, particularly bullheads and carp. On many occasions while sampling for water quality, we noted schools of black bullheads ranging in size from juveniles to adults. Examples of lakes where this was observed include: Elk Lake, Elm Lake, High Lake, Marble Lake, Morse Lake, Rice Lake, Silver Lake, and Twelve Mile Lake.

Aquatic Invertebrate Survey

The restoration draw-down and refill process may have an effect on the re-colonization of aquatic macroinvertebrates, which could be reflected in species abundance and diversity. In order to accurately assess lake health using aquatic invertebrates as an indicator requires that the site has been restored for at least a full growing season prior to the start of the study. While restored sites, based on this three year study, did not show the response in increased species richness and abundance we anticipated with greater plant colonization and improved water quality we suggest taking a closer look at revamping and intensifying invertebrate sample collection on Iowa's shallow lakes. Additional in-lake invert sampling locations would capture a more representative sample by potentially sampling multiple in-lake habitats.

The use of Minnesota's IBI to calculate overall lake health used metrics or variables that included: number of leech taxa, count of corixidae, percent corixidae, count of all bugs and beetles, number of odonate taxa, ETSD metric (numbers of mayflies, caddisflies, fingernail clams, and dragonflies), number of snail taxa, and total sensitive taxa metric (number of taxa for leeches, odonates, mayflies and caddisflies, snails, macrocrustaceans, dipterans, and fingernail clams).

Functional feeding groups (FFG) were also analyzed by site and no trends were noticeable in any sites, restored or non-restored. Very minimal abundances at many sites make it challenging to tease out trends in inverts and to make accurate categorization of FFG. A more comprehensive assessment of invertebrate composition will need to be conducted by Iowa DNR as part of continued future monitoring.

Good water quality and healthy aquatic plant communities become evident through shallow lake improvement projects.

Aquatic Macrophyte Survey

Abundance of macrophytes in restored sites versus non-restored sites displays benefits of restoration from a plant community abundance and diversity standpoint. The turbid water present in non-restored shallow lakes proved to be a limiting factor on submerged, as well as emergent, plant abundance. Non-restored lakes submerged plant communities were comprised of: sago pondweed, narrow-leaf pondweed, naiad, chara, and coontail. These plants were found primarily in Marble and West Hottes Lakes. Compared to all other non-restored sites, these two lakes happen to be the closest representatives for water clarity as found at restored lakes.

Phytoplankton and Zooplankton Survey

Cryptophyta from www.photomacrography.net

In a shallow lake environment, the bottom of the food chain is comprised of phytoplankton and zooplankton species. Phytoplankton are small plant organisms, such as algae, which require sunlight as well as available nutrients to grow. Zooplankton are small animal organisms which feed on phytoplankton.
When comparing the average biomass of both phytoplankton and zooplankton, it was found that the non-restored lakes had considerably higher biomasses. This is not surprising considering the fact that the nutrient levels in the non-restored lakes are much higher than the nutrient levels in the restored systems. High levels of phosphorous in particular have been shown to increase the phytoplankton biomass in lakes. When comparing the study sites, non-restored lakes have higher concentrations of phosphorous, on average, than the restored sites. The phytoplankton biomass of a system has a direct effect on the zooplankton biomass. Since zooplankton primarily feed on phytoplankton, the zooplankton population will increase or decrease based on the availability of this food source.

A healthy system typically consists of a phytoplankton community which is comprised of a low proportion of cyanobacteria, and higher proportions of chlorophyta and diatoms. For the study sites, it was found that the non-restored lakes had a much larger proportion of cyanobacteria than chlorophyta and diatoms, while the phytoplankton composition in the restored lakes consisted of a much smaller proportion of cyanobacteria than chlorophyta and diatoms. The phytoplankton assemblage indicates that the restored lakes are considerably healthier than the non-restored lakes. This conclusion is supported by the zooplankton assemblages, as the species richness values were higher in the restored systems than in the non-restored systems, indicating that there is a higher level of biodiversity in the zooplankton communities of the restored lakes.

Summary and Recommendations

A study of 17 north-central and northwestern Iowa shallow lakes was conducted from 2010 to 2012 to provide data for assessing restoration successes and failures based on biological, chemical, and physical trends for restored and non-restored sites. Some of the lakes had pre-study sampling data as a result of the ongoing monitoring efforts at the Iowa DNR in collaboration with Ducks Unlimited and other internal and external stakeholders. A few general observations are as follows:

- All lakes have highly agricultural watersheds, which is typical for these two regions. Agriculturally dominated watersheds have higher sediment and phosphorus inputs.
- All lakes in this study are quite shallow with maximum depths < 2 meters (6 feet).
- Four lakes (Big Wall Lake, Dan Green Slough, Diamond Lake, and Four Mile Lake) have been restored from the turbid water state to the clear water state.
- Precipitation fluctuations ranged from an extremely wet year in 2010 to a drought year in 2012, while 2011 was near normal precipitation for these two regions.
- All lakes are subjected to wind mixing. This mixing brings suspended sediments and TP back into suspension periodically during the summer. The TP may contribute to algal blooms, while elevated TSS may lead to light limitation in other instances causing lower than expected algal and plant growth. In almost all cases, transparency is very low, typically <35 cm (<14 inches) as a summer average for non-restored sites, while restored sites average >75 cm (>29 inches). High TSS, algal blooms, and generally low transparency may limit the establishment of macrophytes in many lakes.
- Most of the lakes are very nutrient rich, especially non-restored sites. The elevated TP concentrations contribute to high cholorophyll a, which results in nuisance blooms of algae. Many of the lakes are dominated by blue-green algae that float near the surface and contribute to scums and odors that are common during the summer months.
- Emergent and submergent macrophytes were very common at restored lakes, but not common on the majority of non-restored lakes. Narrow-leaf cattail, softstem bulrush, arrowhead, and burr reed were prevalent emergent macrophytes while coontail, sago pondweed, and bladderwort were a few of the dominant submergent macrophytes.
- Aquatic invertebrates did not show a trend for system health as anticipated between restored and non-restored sites. A more comprehensive assessment of invertebrate composition will need to be conducted by Iowa DNR as part of continued future monitoring.
- The total biomasses of zooplankton and phytoplankton were higher in the non-restored lakes than in the restored lakes. The high amounts of nutrients in the non-restored lakes cause large algal blooms, which zooplankton feed on, thus increasing their population.
- Phytoplankton composition in the restored lakes consisted of a much smaller proportion of cyanobacteria than chlorophyta and diatoms, while the reverse of this was seen in the non-restored lakes, indicating that the water quality of restored lakes is very good when compared to the non-restored lakes.
- Some of the lakes support a sport fishery that includes panfish, northern pike, yellow perch, and walleye. Because of their shallow depth and high productivity winterkill is common.

- Rough fish, like black bullhead and common carp, are common in almost all non-restored lakes. These species often survive partial winterkills. They can have a major impact on rooted plant populations and water quality, contributing to increased turbidity, TSS, and TP.

The results of this three year monitoring project will help demonstrate the success and importance of shallow lake restoration efforts to the general public, resource managers and our funding partners. Continued monitoring efforts will also provide a long-term regional data set of pre- and post-restoration conditions of Iowa's shallow lakes. Ultimately, this data will be used to help develop more robust habitat management plans that outline specific objectives and triggers (i.e., conditions that warrant a future drawdown) and guide future conservation planning decisions.

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Appendix 1. Shallow lakes monitored as part of the 2010 to 2012 project.

SHALLOW LAKE	STORET	COUNTY	UTM (X)	UTM (Y)	2010	2011	2012
Big Wall Lake	22990005	WRIGHT	446871	4718555	X	X	X
Blue Wing Marsh	22740005	PALO ALTO	347738	4781089	X		
Cheever Lake	22320007	EMMET	347514	4803733			X
Dan Greene Slough	22100004	CLAY	336509	4786646	Restored	X	X
Diamond Lake	29300002	DICKINSON	322837	4816754	X	X	X
Eagle Lake	23320002	EMMET	352099	4816540			X
East Hottes Lake	22300016	DICKINSON	327641	4816584	X		
Elk Lake	22100005	CLAY	342964	4771902	X	X	X
Elm Lake	22990006	WRIGHT	444363	4735405	X	X	X
Four Mile Lake	22320008	EMMET	345448	4806362	X	X	X
High Lake	22320003	EMMET	361502	4795905	X		X
Marble Lake	22300017	DICKINSON	327378	4815752	X	X	X
Morse Lake	22990004	WRIGHT	443394	4743188	X	X	X
Rice Lake	22950001	WINNEBAGO	458979	4804543		X	X
Silver Lake	22980001	WORTH	466172	4814288	X	X	Restored
South Twin Lake	22130004	CALHOUN	364032	4702226	X		
Sunken Grove Lake	29300004	DICKINSON	327879	4816380	X		
Twelve Mile Lake	22320009	EMMET	347612	4794531		X	X
Ventura Marsh	22170006	CERRO GORDO	460828	4774386	X		Restored
Virgin Lake	22740004	PALO ALTO	345873	4773975	X	X	
West Hottes Lake	22300018	DICKINSON	326600	4816083	X	X	X
West Swan Lake	22300019	EMMET	341663	4813841		X	X
West Twin Lake	22410004	HANCOCK	440088	4754202	X	X	X

Appendix 2. Budget Summary

Table 3 below provides a detailed project budget summary. The DNR Wildlife, Fisheries and Lakes Restoration Bureaus have agreed to provide at least $60,000 in cost-share funding during the 3-year project period. DU has also agreed to provide $16,800 (over 3 years) in additional cost-share assistance to help support this project. Sampling and analysis costs are based on the University of Iowa Hygienic Laboratory fees. DU's donated indirect expenses are based on a federally approved indirect rate (10%) as determined by an external audit.

Table 3. Iowa Shallow Lake Monitoring & Assessment Budget (2010-2012)			
	Description	**JV Flex Fund Request**	***Non-Federal Cost Share**
Wetland Monitoring & Assessment - Continued Program Growth & Development			
Data Collection, Analyses & Reporting	3 years of sampling data to assess the physical, chemical and biological parameters of 16 priority shallow lakes and wetlands (~$3,000/site/year).	$ 63,000	$ 76,500
Equipment & Supplies	Field sampling gear, computer software and GIS project maps	$ 3,000	$ -
Travel Expenses	$2,000/year over the 3-year project period	$ 6,000	$ -
Grant Administration	DU staff time (2 days/year over 3 years)	$ 3,000	$ -
DU Indirect Costs	10% of DU's grant administration costs	$ -	$ 300
	Subtotal	**$ 75,000**	**$ 76,800**
	TOTAL 3-YEAR PROJECT COST		**$151,800**

*Non-federal cost-share includes $60,000 (cash) from Iowa DNR and $16,800 ($16,500 cash; $300 donated indirects) from Ducks Unlimited over the 3-year project period.

Appendix 3. Physical parameters at restored* and non-restored** lakes by month from 2010 to 2012 and descriptive statistics by year and parameter.

	Secchi Depth (cm)			Temperature (°C)			Conductivity (mS/cm)			Dissolved Oxygen (mg/L)			pH			Turbidity (NTU)		
Restored Lakes	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
May	71.67	91.58	98.75	18.62	15.47	19.70	385.22	437.17		13.48	8.64	2.90	8.41	8.20	8.17	2.02	2.31	2.63
June	91.67	88.25	93.50	22.00	20.86	21.74	385.71	347.75	376.25	9.50	7.92	12.56	8.96	8.62	8.98	3.31	1.82	2.08
July	71.56	78.17	54.50	24.50	24.93	27.82	421.83	348.00	439.00	6.59	5.92	8.01	8.31	8.39	8.47	3.36	3.70	7.58
Aug	62.11	75.33	37.25	22.85	22.61	21.65	448.03	428.92	378.50	4.16	2.31	6.08	7.76	6.85	9.10	6.37	5.10	4.92
Sept	71.89	81.33	51.00	17.10	15.25	18.77	446.57	444.92	377.50	1.38	3.18	6.80	7.50	7.35	9.13	2.14	4.83	17.22
Average	73.78	82.93	67.00	21.01	19.82	21.94	417.47	401.35	392.81	7.02	5.59	7.27	8.19	7.88	8.77	3.44	3.55	6.88
Minimum	62.11	75.33	37.25	17.10	15.25	18.77	385.22	347.75	376.25	1.38	2.31	2.90	7.50	6.85	8.17	2.02	1.82	2.08
Maximum	91.67	91.58	98.75	24.50	24.93	27.82	448.03	444.92	439.00	13.48	8.64	12.56	8.96	8.62	9.13	6.37	5.10	17.22
St. Deviation	10.83	6.82	27.42	3.06	4.32	3.52	31.02	49.14	30.81	4.69	2.80	3.51	0.57	0.75	0.43	1.75	1.47	6.17

***Note: Restored Lakes include Big Wall Lake, Dan Green Slough, Diamond Lake, and Four Mile Lake**

	Secchi Depth (cm)			Temperature (°C)			Conductivity (mS/cm)			Dissolved Oxygen (mg/L)			pH			Turbidity (NTU)		
Non-Restored Lakes	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
May	56.50	53.80	26.00	18.58	15.24	19.59	335.40	319.60		6.34	10.22	1.77	7.89	8.36	8.66	19.55	22.09	91.00
June	41.80	37.55	29.10	21.92	23.18	21.60	319.53	315.64	341.70	8.83	6.52	11.15	8.19	8.23	8.83	48.80	63.06	105.52
July	31.20	30.09	24.40	26.47	24.93	28.38	338.59	284.55	325.70	5.56	6.79	8.41	8.80	8.46	8.68	34.17	75.04	75.94
Aug	27.89	29.00	15.00	24.93	25.40	22.33	296.69	268.91	285.80	3.50	2.11	6.43	8.62	8.22	9.59	31.30	68.43	96.88
Sept	18.89	26.45	11.10	17.71	17.26	18.81	291.24	258.64	270.70	1.25	2.23	5.91	8.09	9.00	9.47	59.08	75.79	153.79
Average	35.26	35.38	21.12	21.92	21.20	22.14	316.29	289.47	305.98	5.10	5.57	6.73	8.32	8.45	9.05	38.58	60.88	104.63
Minimum	18.89	26.45	11.10	17.71	15.24	18.81	291.24	258.64	270.70	1.25	2.11	1.77	7.89	8.22	8.66	19.55	22.09	75.94
Maximum	56.50	53.80	29.10	26.47	25.40	28.38	338.59	319.60	341.70	8.83	10.22	11.15	8.80	9.00	9.59	59.08	75.79	153.79
St. Deviation	14.43	11.09	7.68	3.83	4.65	3.77	21.70	27.34	33.25	2.87	3.43	3.46	0.38	0.32	0.45	15.49	22.30	29.52

****Note: Non-Restored Lakes include Elk Lake, Elm Lake, High Lake, Marble Lake, Morse Lake, Rice Lake, Silver Lake, Twelve Mile Lake, Virgin Lake, West Hottes Lake, West Swan Lake, West Twin Lake**